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CORONAVIRUS DISEASE (COVID-19): SOCIO-ECONOMIC SYSTEMS IN THE POST-PANDEMIC WORLD: DESIGN THINKING, STRATEGIC PLANNING, MANAGEMENT, AND PUBLIC POLICY

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CORONAVIRUS DISEASE (COVID-19): SOCIO-ECONOMIC SYSTEMS IN THE POST-PANDEMIC WORLD: DESIGN THINKING, STRATEGIC PLANNING, MANAGEMENT, AND PUBLIC POLICY

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Editorial: Coronavirus disease (COVID-19): Socio-economic systems in the post-pandemic world: Design thinking, strategic planning, management, and public policy

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Editorial on the Research Topic
Coronavirus disease (COVID-19): Socio-economic systems in the post-pandemic world: Design thinking, strategic planning, management, and public policy

Overview

The declaration of the COVID-19 pandemic by the World Health Organization on March 11, 2020, led to unprecedented events. All regions of the world participated in implementing preventive health measures such as physical distancing, travel restrictions, self-isolation, quarantines, and facility closures. The pandemic started global disruption of socio-economic systems, covering the postponement or cancellation of public events, supply shortages, schools and universities' closure, evacuation of foreign citizens, a rise in unemployment and inflation, misinformation, the anti-vaccine movement, and incidents of discrimination toward people affected by or suspected of having coronavirus disease. Attempts have been made to protect the oldest age group at risk, but in many cases, this has led to over-restriction and age discrimination.

The rationale for working on the Research Topic "Socio-economic systems in the post-pandemic world: Design thinking, strategic planning, management, and public policy" was the need to start reflecting on resilience and lessons learned from this public health event that revealed the global unpreparedness in critical areas. Also, the pandemic triggered

both top-down (e.g., policy tools toward labor markets) and bottom-up (e.g., social and technological innovations in education) responses that needed more in-depth analyzes.

This Research Topic covers interdisciplinary contributions addressing new thinking, challenges, and transformations required for post-pandemic global, national, regional, and local realities. The presented Research Topic combines studies focused on recognizing the actions and interventions leading to the recovery of socio-economic systems during the tail end and after the pandemic. The studies delivered recommendations regarding, among others, the care of vulnerable, planning socio-economic restart, and imagining the "new normal."

The presented Research Topic includes 27 articles prepared by 113 authors from all continents. This set of texts contains seven types of papers covering: 14 original research articles (Beno and Hvorecky; Bhandari et al.; Bjursell et al.; Breitenbach et al.; El Deeb; Ferchiou et al.; Kieslinger et al.; Liu et al.; Musango et al.; Poppe; Rasul et al.; Rivera-Rodriguez and Urdinola; Suomi et al.; Chen et al.), two perspective articles (Lee and Kang; Takewaki), four review articles (Contreras et al.; Kumar, Malla et al.; Singu et al.; Hamid and Mir), one study protocol article (Marston et al.), three opinion articles (Lever and Safra; Sciacchitano and Bartolazzi; Vlacha and Feketea), one conceptual analysis article (Auriemma and Iannaccone), and two brief research reports (Kumar, Kodidela et al.; Sun et al.).

The editors have identified six themes underpinning and linking together the finally selected papers. The identified macro themes help to distinguish the main contribution focus and the areas of application of the published research. However, these studies are also a testimony of the pandemic's impact on each and every significant aspect of our societies.

Theme I: Resource management of healthcare systems and public health strategies

This theme covers papers that explore the interrelationships between socio-economic conditions, public health strategies, and the preparedness of healthcare systems during the pandemic. For example, Singu et al. explore the link between population characteristics and the emergence and transmission of COVID-19 in the United States, focusing on social determinants and their impact on health outcomes. The paper by Poppe focuses on reconsidering the efficacy of public health strategies used in developed countries in different socio-economic settings, such as Latin America, where informal and casual employment may be prevalent. This study reveals that public health policies have varying degrees of adherence, hence efficacy, depending on country-related macroeconomic indicators. Similarly, the paper by Musango et al. highlights the importance of existing population characteristics and socio-economic contexts when calculating the value money of the death toll in Mauritius. The study applies a human capital approach to determine a total discounted money value for the human lives lost in the country.

Several papers in this Research Topic have modeled possible responses to the COVID-19 pandemic in the context of informed decision-making and resource allocation. In the article by Ferchiou et al., simulation is used to figure out pandemic preventative measures for various population groups and transmission rates. The model leads to the identification of several lockdown strategies and recommendations for policymakers regarding biosecurity compliance that may be achievable by monitoring general population behavior. Another modeling study by Rivera-Rodriguez and Urdinola was conducted to support policymakers in developing countries, such as Colombia, to decide what public health tools, e.g., lockdown, should be developed based on the foreseeable needs of intensive care unit beds. Bhandari et al. apply hazard modeling to forecast the demand for hospital beds during the pandemic, looking at the impact of selected population variables. A final contribution that used modeling, particularly technical efficiency analysis, is by Breitenbach et al. This work aims to determine the efficiency rate in country-specific response to COVID-19. The analysis was undertaken over a sample of 36 countries representing 90% of the global infection cases and considered pandemic-related infection and death cases in the computation. The developed model highlighted that despite allocating resources for healthcare systems, the efficiency is likely to degrade due to the lack of a systematic approach in responding to the critical challenges raised by the pandemic.

Theme II: COVID-19 and regulatory issues

The COVID-19 state of emergency raised pressure on regulatory frameworks worldwide due to the urgent demand for the development of effective policy tools not only related to health (Benton et al., 2020). The paper by Lee and Kang shows that the authorities needed to address the challenge of managing various forms of regulations related to COVID-19 in people's everyday lives. For example, South Korea has implemented streamlined fast-track services for the biotechnology industry to produce test kits swiftly. The mentioned study focuses on the precision regulation approach that delivers the right regulation methods for the right group of people at the right time. Another essential regulation issue that Sciacchitano and Bartolazzi underline is the importance of transparency in negotiating COVID-19 vaccine production and final vaccine price. Transparency could help avoid misconceptions and strengthen the collaboration between healthcare systems in European Union countries. Transparency is also essential to avoid "vaccine nationalism," which undermines global efforts to ensure fair access to vaccines for everyone and facilitates

the development of viral mutations. According to the study by Lever and Safra, one of the most noticeable reactions of governments to COVID-19 has been to impose lockdowns and restrictions on freedom of movement and association. These decisions can be temporary measures to control or mitigate the spread of the epidemic while waiting for the vaccine to be developed. However, pharmacological solutions should not prevent considering the endogenous factors in the societies which helped catalyze this pandemic.

Theme III: Environmental effects

One of the initial observations related to the COVID-19 pandemic was its impact on the environment and sustainability management (Barreiro-Gen et al., 2020). Kumar, Malla et al. show that societies and the environment have witnessed apparent positive and negative impacts of lockdowns. Closures of facilities and movement restrictions altered energy demand patterns and caused an economic downturn. Such a situation provided unprecedented insights into the dynamics of natural and built environments that can lead to viable conservation paths and help create new recovery environmental pathways. Another study by El Deeb presents the spread of the COVID-19 infection in Lebanon. The author shows that combining and understanding the disease's spatial, demographic, and geographic aspects over time allows for regionally and locally adjusted health policies and measures that could provide higher social and health safety. The contribution from Liu et al. aims to analyze the potential spread of the coronavirus through rail transport. The authors also present recommendations for controlling the spread of the disease in Wuhan, China. The study takes into account the effectiveness of control measures such as lockdown, the use of masks, sanitization, and social distancing for railway authorities and passengers. In the study by Takewaki, "resilience" in architecture and engineering has been investigated primarily in terms of conventional natural disaster risks. The paper shows that architectural designers and engineers have an important mandate to think about the functions of buildings and their surroundings in the disease spread. Finally, Hamid and Mir provide a closer look at the food and the agriculture sector that was hit by lockdowns and market shutdowns which have endangered the supply of agricultural and food items across country borders. Especially food security and supply chain stability has been affected in emerging and less developed countries.

Theme IV: Macro socio-economic effects

The COVID-19 pandemic has also impacted various areas of socio-economic development by, for example, a rise in economic uncertainty and challenges to monetary policy, fiscal policy, and trade policy (McKibbin and Fernando, 2021). The paper by Rasul et al. shows that South Asian states have encountered a challenging situation culminating from, among others, a large population, inadequate health facilities, high poverty rates, low socio-economic conditions, and limited access to water and sanitation. The need to contain the COVID-19 spread has led to lockdowns with effects on economic growth, increasing the fiscal deficit, monetary burden, and macroeconomic instability. According to Auriemma and Iannaccone, the adoption of lockdowns has precipitated socio-economic development by generating radical changes in daily life at the national, supranational, and international levels. For example, in Italy, the suspension of commercial activities led to a search for smart employment solutions but also to the digital divide and new forms of relationships. The study by Marston et al. shows that using digital technologies is an alternative to maintaining economic and social activities during physical distancing adherence. The paper describes how the pandemic impacted social interactions, including the association of the use of digital technologies with psychological wellbeing and levels of loneliness. Another side of technology-related issues has been investigated by Kieslinger et al., who studied the lack of medical hardware supplies during the COVID-19 pandemic. This situation led to more significant innovation in healthcare systems, especially the local production of COVID-19-compliant healthcare products (e.g., face shields and medical supplies), with implications for reducing dependencies on international supply chains and mainstream mass production.

Theme V: Labor and employment-related challenges

The COVID-19 pandemic caused a shock for the labor markets worldwide, including changes in workforce mobility, work reorganization, and applying various labor market policy measures to decrease the risk of mass unemployment (International Labour Organization, 2020). The contribution by Sun et al. is based on a survey among financial managers before the coronavirus disease peaked in China. The authors analyzed the managers' coping strategies, the risk perception directly caused by COVID-19, and the indirect effect that refers to managers' fear that they will not make timely adjustments. Contreras et al. explain that companies had to switch from physical presence to telework from one moment to the next. The existing knowledge of teleworking and e-leadership played a crucial role in the reorganization process. As a result, the leading companies in this field have enjoyed a considerable advantage in building new production structures and reaching advantages in the market. Kumar, Kodidela et al. write that the combination of decreased productivity and staying at home is likely to compromise wellbeing by causing stress and anxiety.

However, organizing virtual sessions to learn about workers' motivation and listen to their experiments helped decrease perceived and COVID-19-related stress scores. Also, the study by Suomi et al. showed that the difference in perceptions of the employed and unemployed was attenuated during COVID-19, with benefitting recipients perceived as more employable and conscientious than in the pre-pandemic period. These results add to knowledge about the determinants of welfare stigma, highlighting the impact of the global economic and health crisis on the perception of others. Finally, Beno and Hvorecky surveyed companies shortly before the epidemic. Given the situation, they decided to repeat the survey during a different phase of a pandemic to find out the effectiveness of e-working and the causes of decreased work productivity.

Theme VI: Education-related challenges

The COVID-19 pandemic has also impacted risk management in educational institutions, for example, mental health maintenance, staff mobility control, and online education schemes (Tadesse and Muluye, 2020). Vlacha and Feketea underline that the spread of COVID-19 and other winter-related common viral infections may co-exist while prevalent among children. Resultantly, there may be consequences from children's lack of school attendance ranging from family's financial security to support the children's educational needs and emotional wellbeing with implications for childcare for affected parents. In essence, there is a need for the children to attend school regularly and yet facilitate students' protection from COVID-19. Bjursell et al. show that the pandemic has also impacted participation in lifelong learning, with differences between age groups, nations, sectors, and professions. While a study by Chen et al. analyzes shifts in academic activities from offline to online and/or virtual operations. The research focuses on sustainable knowledge-sharing willingness in virtual academic communities.

Conclusion

The studies presented in this Research Topic allow identifying at least eight directions for further investigations. These are: (1) digital innovations, including artificial intelligence and robotic solutions as well as innovation policy in the public health and health sector; (2) tensions between national and international health policies and regulations; (3) redesign and resilience in the trade policies, transport systems, and supply chains; (4) emerging transformations and inequalities at the labor markets; (5) planning, management, governance, and evaluation of governmental interventions related to the pandemic (see also Dunlop et al., 2020); (6) comparative public policy studies focusing on differences across nations and policy transfer (see also Liu and Geva-May, 2021); (7) impact of the pandemic on trust and risk management and communication; and (8) the advancements in the usage of design thinking, co-production, co-design, social innovation, and citizen science.

Author contributions

All editors of this Research Topic have contributed to this Editorial as well as to the selection and review of the papers accepted in this Research Topic. All authors listed have made a substantial, direct, and intellectual contribution to the work and approved it for publication.

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REVIEW
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Impact of Social Determinants of Health on the Emerging COVID-19 Pandemic in the United States

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A novel coronavirus (2019-nCoV) caused a global pandemic in the months following the first four cases reported in Wuhan, China, on December 29, 2019. The elderly, immunocompromised, and those with preexisting conditions—such as asthma, cardiovascular disease (CVD), hypertension, chronic kidney disease (CKD), or obesity—experience higher risk of becoming severely ill if infected with the virus. Systemic social inequality and discrepancies in socioeconomic status (SES) contribute to higher incidence of asthma, CVD, hypertension, CKD, and obesity in segments of the general population. Such preexisting conditions bring heightened risk of complications for individuals who contract the coronavirus disease (COVID-19) from the virus (2019-nCoV)—also known as "severe acute respiratory syndrome coronavirus 2" (SARS-CoV-2). In order to help vulnerable groups during times of a health emergency, focus must be placed at the root of the problem. Studying the social determinants of health (SDOH), and how they impact disadvantaged populations during times of crisis, will help governments to better manage health emergencies so that every individual has equal opportunity to staying healthy. This review summarizes the impact of social determinants of health (SDOH) during the COVID-19 pandemic.

Keywords: SDOH, SARS-CoV-2, COVID-19, social inequality, public health, food, economy, education

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INTRODUCTION

The novel coronavirus (2019-nCoV) spread rapidly throughout China during the Chinese New Year in late January of 2020, a time of increased domestic and international travel for Chinese people. The first four cases of the novel coronavirus were reported on December 29, 2019. All four cases were linked to the Huanan Seafood Wholesale Market in Wuhan, a city with more than 11 million people and the capital of Hubei province in central China. The symptoms were described as a pneumonia of unknown etiology (1). Early cases show history of contact with the seafood market. Later and more recent cases were found to be transmitted via human-to-human contact (2). The disease caused by 2019-nCoV was named COVID-19 by the World Health Organization (WHO) on February 11, 2020 (3). The CDC confirmed that individuals with preexisting diagnoses of asthma, cardiovascular (CVD), hypertension, chronic kidney disease (CKD) and/or are elderly, immunocompromised, or obese have higher risk of severe illness from COVID-19 (4). Of the listed at-risk health demographics, asthma, CVD, hypertension, CKD, and obesity can be caused by

discrepancies in socioeconomic status (SES). The CDC reports that 94% of patients who have died from COVID-19 had at least one preexisting condition (5). Because these conditions specifically put an individual at higher risk of being infected with SARS-CoV-2, these vulnerable populations must be given the resources needed to endure infectious outbreaks. This review summarizes the impact of social determinants of health (SDOH) during a pandemic of COVID-19. It can provide essential information to support the government's decision-making body to strategically manage health emergencies at community, national, and even international levels in the future if a similar situation was to arise. Calculated measures can be taken to prevent or reduce further transmissions in a vulnerable population that is at risk.

SOCIAL DETERMINANTS OF HEALTH

The social determinants of health (SDOH) are social and economic conditions that are categorized into five key determinants as summarized in **Figure 1**. Health and health care, social and community context, neighborhood and built environment, education, and economic stability (6). Health and health care include access to health care, access to primary care, health insurance coverage, and health literacy (7). Low health literacy can cause patients difficulty with navigating the complex healthcare system and understanding medical advice or prescriptions. Individuals without health insurance are less likely to utilize or even have access to primary care, which makes detecting and managing chronic conditions, such as CVD, asthma, diabetes, and cancer, difficult. Social and community context are the circumstances a person lives, learns, and works in. This domain of SDOH includes community involvement and discrimination. Lower mortality rates are associated with social and community support and cohesion. Neighborhood and built environment include housing, neighborhood, transportation, access to healthy foods, air quality, water quality, and access to green space (7). Air pollution has been shown to be associated with incident asthma. The CDC has confirmed that individuals with asthma are at higher risk for severe illness from COVID-19 (8). Safety plays a major role in health. People are more likely to walk or run outside if they feel safe in their neighborhood. Without the worry about crime and danger, safe neighborhoods also allow people to maintain good mental health. Immune function is influenced by psychological stress. Algren et al. state that individuals living in deprived neighborhoods were observed to have more stress when compared to those living in non-deprived neighborhoods. Stressors of those living in deprived neighborhoods include, "overcrowding, high crime rates, perceived danger, poor transportation, poor housing, disrepair, limited services, poor infrastructure, and a lack of social support" (9). Education includes high school graduation, enrollment in higher education, and language and literacy. The higher one's level of education, the higher his or her life expectancy is (7). It is important to disclose information regarding health in a patient-specific manner, taking into account the patient's education level. Economic stability includes

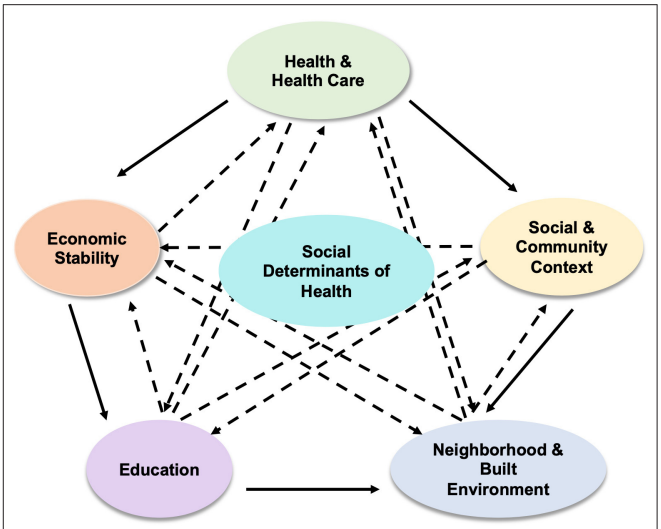

FIGURE 1 | The five domains of social determinants of health (SDOH).

employment, poverty, food security, and housing stability. The American Medical Association (AMA) states that as the poverty level increases, the percentage of adults who are 25 years and older with an activity-limiting chronic disease increases (7). Unemployment impacts an individual's health in many ways, as it has associations with depression, domestic violence, substance abuse, and physical illness.

Specific examples of SDOH include income, education, employment, and social support (10). Simply put, they are conditions into which one is born, grows, lives, works, and ages (11). They look at the person as a whole. Altogether, these conditions impact health status of individuals and communities. Disparities in any of these conditions are translated into a measure of social hierarchy called socioeconomic status (SES). The lower individuals are on the spectrum of SES, the poorer health outcomes they face. Due to poor outcomes, life expectancy decreases for those at the lower end of the spectrum (10). Socioeconomic inequality piles health complications on top of the financial woes already burdening disadvantaged segments of the population.

The five SDOH are interrelated and played major role during COVID-19 pandemic. For example, education level of an individual can impact his or her occupation, which determines economic stability and income level, which can impact the type of healthcare the individual is eligible for and what neighborhood the individual lives in, which then impacts the social and community context the individual is surrounded by and those factors played important role in current COVID-19 pandemic. Therefore, one can conclude that socioeconomic factors play a key role in infection and mortality rates. Specific examples include some county's in New York, such as Bronx, Brooklyn, and Queens have suffered higher mortality rate compared to other county's suggested that large of population of individuals with low economic status lived in these areas. Another example to consider is from the perspective of a child growing up in a family

that does not have much economic stability. The child's parents have low-income jobs, which forces them to live in poverty-stricken neighborhoods that may not have a great school system. This child will not obtain the same quality of education as a child that lives in an affluent neighborhood that has a richer school district. Since, public schools in the U.S. are funded by local, state, and federal governments (12). Funding comes from income and property taxes. Affluent neighborhoods and districts collect more taxes; therefore, they have more funding. Low-income districts collect less funding and have substandard school facilities and teachers who are the least qualified (12). Therefore, below average quality of education will not lead to high college admission test scores, which will keep the child out of top colleges if he or she chooses to pursue a college education. Even with a low-tier college education, the child may not have many high-income job opportunities. This will land the child in the same position as his or her parents, with a low-income job living in a poverty-stricken neighborhood. Ham et al. (13) state that children living with their parents in poverty-stricken neighborhoods are more likely to end up in the same situation themselves later in their life. The five determinants can be thought of as a cycle of events that impact one another rather than as individual entities even in current COVID-19 pandemic.

HEALTH AND HEALTHCARE

Health Literacy

Health literacy is defined by the U.S. Department of Health and Human Services (HHS) as "the degree to which individuals have the capacity to obtain, process, and understand basic health information needed to make appropriate health decisions" (14). This includes the ability to read and understand health-related pamphlets, prescriptions, written instructions from a healthcare provider, etc. Not being able to read or understand health-related information makes it difficult for individuals to take care of themselves, even if the awareness to do so is present. Low health literacy is associated with poorer health outcomes. Certain population groups have been noted to have low health literacy compared to other groups (14). Those who are living in poverty, not highly educated, from a certain race/ethnic group, or with disabilities are more likely to have low health literacy (14). Patients who demonstrate low health literacy may have high overall literacy and high verbal fluency, which causes the patient to present as having high health literacy. It is important to recognize people who may have low health literacy especially during times of a pandemic, because health literacy is an important means of preventing communicable diseases, such as COVID-19. Understanding infectious diseases to a certain degree, including mode of transmission and viability of pathogens, will help people readily accept the circumstances in situations like this rather than question the recommendations. Health literacy can allow people to understand their responsibility of adhering to social distancing and other recommended measures during the COVID-19 pandemic and the reasoning behind the measures being taken to prevent the spread of the virus.

A Gallup poll conducted in the months of April and May of 2020 looked at how many Americans considered social distancing to be significant by assessing their confidence level in the impact social distancing has on reducing the spread of COVID-19. Further, determined whether each group that was divided by confidence level followed social distancing. The study found that 54% of Americans were "very confident" and 31% were "moderately confident" in their belief that social distancing helps save lives during COVID-19 pandemic (15). However, 14% of Americans who participated expressed skepticism about social distancing and its role in saving lives. Overall, 88% of Americans who participated in the poll reported that they "always" or "very often" practiced social distancing, which included measures such as avoiding crowded places and leaving their homes unnecessarily. Of those who were "very confident" or "moderately confident" that social distancing makes a difference, 95 and 87% reported that they "very often" practiced social distancing, respectively. Fifty-seven percentage of those who expressed skepticism "very often" practiced social distancing. The percentages were drop when it comes to "always" practicing social distancing. Seventy-one percentage of those who were "very confident" that social distancing making a difference "always" practiced it, whereas 47% of those who were "moderately confident" "always" practiced it. Only 27% of those who were skeptical "always" practiced social distancing. Therefore, health literacy was played a major role in whether an individual understands a health emergency situation, such as COVID-19 pandemic, and whether he or she will follow recommendations, such as social distancing.

Access to Health Care and Primary Care

Access to health care is described as the "timely use of personal health services to achieve the best possible health outcomes" by the National Academies of Sciences, Engineering, and Medicine (14). Many people face barriers to health care, which may hinder their ability to take responsible actions toward their well-being. Barriers include limited or no access to transportation for health appointments, lack of health insurance, limited education about health care, limited health care resources, provider hours limited to work hours, etc. Lack of health insurance is usually seen in populations with lower incomes and minorities. A study by Gallup and West Health found that 14% of adults in the U.S. revealed that they would not seek healthcare if they experienced a fever and dry cough (16, 17). Fever and dry cough are the most common symptoms of COVID-19. When adults were specifically asked whether they would seek healthcare if they had believed they had been infected with COVID-19, 9% still answered that they would not (16). The individuals that reported that they would not seek healthcare were non-white adults under the age of 30 who had a high school education or less earning less than a $40,000 income per year (16).

Reluctance to seek healthcare is associated with socioeconomic status. Hispanics and African Americans were less likely to have health insurance compared to non-Hispanic whites (16). Without health insurance, primary care visits may not be feasible, or people may hesitate to use health care resources. This puts those without health insurance at risk

of not being screened for chronic conditions, such as CVD, hypertension, asthma, and diabetes. Access to health care also relies on the availability of resources (14).

Those who are minorities and/or have low incomes already face difficulty-accessing healthcare. Many of them primarily depend on student-run clinics for obtaining healthcare. The University of Nebraska Medical Center College of Medicine has a student-run clinic, called the Student Health Alliance Reaching Indigent Needy Groups (SHARING) clinic, which provides low-cost primary health care and services to the underprivileged populations in the Omaha community. This clinic has been closed due to the COVID-19 pandemic. Therefore, the underserved populations who already face barriers to healthcare now face a barrier to access primary care at these student-run clinics, which are their primary means of maintaining their well-being.

Role of Food Deserts on Cardiovascular Disease

Food deserts are neighborhoods that are defined as low income areas with little access to healthy foods by the U.S. Department of Agriculture (USDA) (18). A study found that there was association between food deserts and cardiovascular risk factors in an Atlanta metropolitan area. They found that income was more strongly associated with CVD risk than access to healthy food (18). Recognizing that income had a greater part than location of residence, they then studied individual income vs. neighborhood income by observing people with low individual income living in low income neighborhoods and compared them with people with low individual income living in high income neighborhoods. Results showed that individual income is associated with higher risk of CVD than neighborhood income or food access. Those with high individual incomes who lived in low-income neighborhoods had lower CVD risk than those with lower individual incomes who lived in low-income neighborhoods (18). Individuals with high income who lived in neighborhoods with poor healthy food access had better cardiovascular profiles compared to individuals with low income living in high-income neighborhoods. This confirms that the perceived association between food deserts and CVD risk is partly due to individual income status rather than access to healthy foods. Further, another study suggested that there is a similar relationship between SES and CVD and found that mortality from CVD is higher in individuals with lower education levels and lower occupational class (19). The correlation between lower income and heightened risk of CVD, with CVD increasing the risk for serious illness related to infection from COVID-19, suggests an inverse correlation between income and COVID-19 health complications.

Role of Food Deserts on Hypertension and Chronic Kidney Disease

Low income has also been associated with hypertension and CKD. Healthier foods, such as fruits and vegetables, tend to be costlier. This makes it hard for low-income families to afford healthy diets. Individuals have access to high amounts of processed meats and fats instead of fruits and vegetables in low-income neighborhoods and food deserts. A qualitative study done by Suarez et al. has revealed that 80.3% of participants living in food deserts and those with low incomes reported that they "always" or "most of the time" have fruit available at home (20). This is compared to 87.0% of participants that do not live in food deserts and are in the highest income category. 71.6% of participants living in food deserts and those with low incomes reported that they "always" or "most of the time" have dark green vegetables available at home compared to 82.0% that do not live in food deserts and are in the highest income category (20). Qualitatively, family income demonstrated a stronger association with diet, blood pressure, and CKD than living in a food desert (20).

The same study also found that serum carotenoids were low in individuals living in food deserts and individuals with low incomes (20). Carotenoids are a measure of fruit and vegetable intake. They also found that average protein, potassium, sodium, calcium, and magnesium intake were lower among individuals living in food deserts and individuals with low incomes. Measuring levels of these minerals gives insight into the measure of dietary acid load in an individual's body. Low levels of these minerals indicate a higher measure of dietary acid load (21). Foods rich in protein (meat, cheese, eggs, etc.) increase acid production in the body. Fruits and vegetables lead to base production. Diets high in acid induce metabolic acidosis, which can lead to hypertension, CKD, insulin resistance, diabetes, and other complications (20). A high dietary acid load has also been linked to obesity (22).

Role of SDOH on Obesity

Food deserts contain more fast food restaurants than grocery stores. Individuals living in a food desert tend to have a poor diet, which increases the risk of obesity (23). Obesity is classified as a BMI greater than or equal to 40 by the CDC (8). Individuals living outside of food deserts have better access to grocery stores and are more likely to have diets consisting of more fruits and vegetables. These individuals are less likely to be at risk of obesity (23). Individuals who are obese are at higher risk of being diagnosed with a breathing disorder known as obesity hypoventilation syndrome, also known as Pickwickian syndrome. It is not clearly understood why this syndrome affects obese individuals, but it is thought that extra fat on the neck, chest, or abdomen may make breathing deeply difficult. This leads to a buildup of carbon dioxide and decreased amounts of oxygen in the blood. Hormones that affect breathing pattern may also be secreted in response to difficulty in breathing (24).

Body mass index (BMI) is calculated by dividing a person's weight in kilograms by the square of their height in meters (kg/m^2). BMI is a screening tool used to determine whether a person is in a healthy weight range, overweight, or obese. A BMI of <18.5 classifies a person as underweight. BMI between 18.5 and <25 is normal. BMI between 25.0 and <30 puts an individual in the overweight range. BMI 30.0 or higher puts an individual in the obese range (25).

A study with 24 patients who tested positive with COVID-19 was conducted in Seattle. Of the 24 patients, 7 were

classified as overweight and 13 as obese. The study showed that 85% of the obese patients required mechanical ventilation (26). Sixty-two percentage of the obese patients died from the virus. Sixty-four percentage of non-obese patients required mechanical ventilation, and 34% of them died from the virus (26). The percentages of requiring mechanical ventilation and deaths are clearly higher in obese individuals compared to non-obese individuals.

A BMI >40 was found to be the second strongest independent predictor of hospitalization in patients with COVID-19 at an academic hospital in New York City (27). A study in France that collected data from 124 patients who tested positive for COVID-19 reported that the ones who required mechanical ventilation were those who had a BMI greater than or equal to 35. The study mentions that the reason behind why patients usually require mechanical ventilation is because of impaired respiratory mechanics, increased airway resistance, and impaired gas exchange (28). In obese individuals, respiratory problems include low respiratory muscle strength, possible due to the extra fat on the neck, chest, or abdomen as mentioned earlier, and low lung volumes due to the extra fat making it difficult to take deep breaths (24, 28). The study also concluded that the disease severity of COVID-19 increased with increasing BMI (28).

SOCIAL AND COMMUNITY CONTEXT

Discrimination

Unfair or unjustified socially structured actions against a certain group or population contribute to discrimination. These actions tend to favor the affluent and powerful population at the detriment of the impoverished population. Discrimination occurs at both the individual and structural level in health care (17). Individual discrimination includes negative interactions between a patient and a health care provider due to race, gender, etc. Negative interactions may limit health care resources and well-being of the patient. Structural discrimination is seen in the form of residential segregation according to race or ethnic groups, unequal job opportunities due to gender, unequal access to quality education, inequalities in incarceration, etc. Forms of structural discrimination can trickle down to affect individuals and populations in terms of health care. Residential segregation plays a major role in the inequalities observed between African Americans and Caucasian populations. African Americans are more likely to live in high-poverty neighborhoods than other Americans. High-poverty neighborhoods consist of low quality and poor schools, limited access to healthcare and jobs, weak social networks, high rates of crime, pollution, and congestion (29). Because of congestion in impoverished neighborhoods, it can be difficult to follow social isolation recommendations. Keeping physical distance from others may not be an option for some families. Many individuals living in poverty are also in a predicament during times like this when people are asked to work from home, because minorities and African Americans are more likely to hold jobs in professions in which it is not feasible to work from home (30). Many Latinos and African Americans are facing the dilemma of having to pay rent and putting food on the table vs. staying home and keeping their families healthy during this COVID-19 outbreak, as they are the ones who work in warehouses, food industry, construction, janitorial services, etc., and these are jobs that cannot be done from home (30). Though race and ethnicity data are available for only 35% of those who have fallen victim to the virus, discrimination is clearly evident in the existing data (31). New York City, the hardest hit city in the U.S., has had more Latinos per capita fall victim to COVID-19 than any other ethnic groups (29). Latinos make up 29% of New York City's population. Approximately 34% of COVID-19 deaths in New York City are of Latinos. African Americans make up 22% of the city's population and 28% of COVID-19 deaths (32). Overall, African Americans are 2.4 times more likely to die from this virus compared to their counterparts of other races. Broken down by state, the statistics are alarming. African Americans make up ∼13% of the U.S. population, and their population as a whole has endured 32% of COVID-19 deaths. On the other hand, Caucasians are disproportionately facing deaths based on which U.S. state they reside in. As a whole, Caucasians are less likely to die than expected at 0.8 times their counterparts (32).

Community Involvement and Social Cohesion

Social support is an important component of an individual's well-being. Social cohesion, one of the terms used to describe social relationships, describes how strong relationships are and whether there is a sense of solidarity among members of a community (14). Social capital, an indicator of social cohesion, measures the extent of shared group resources within a community, perceived fairness, perceived helpfulness, group membership, and trust (14). Researchers found these aforementioned measures of social capital to be inversely correlated with mortality (33). Social capital decreases as income inequality increases. It is believed that social capital is the element that relates income inequality and mortality (14). Social cohesion is associated with lower neighborhood violence, better self-rated health, and less stress/anxiety. Stress has many impacts on the body, including on the immune, cardiovascular, and neuroendocrine systems. A study has showed that higher amounts of social support were associated with lower levels of atherosclerosis in women predisposed to a higher risk for CVD (34). Another study in California demonstrated that social support among Mexican adults served as a barrier against the detriments of the discrimination they faced (35).

It is evident that people and communities have come together during this difficult time. Medical students have been suspended from clinical clerkships, which prevents students from all patient care activities. Across the nation, medical students have been helping out resident physicians and attending physicians who are on the front-line with childcare, pet care, and running errands. Medical students from the University of Nebraska Medical Center have also been utilizing time off from clinical clerkships by volunteering in the community. Those who know how to sew have been sewing masks for front-line workers due to a shortage of personal protective equipment (PPE). Individuals have been running errands for the elderly who are more vulnerable to falling ill with the virus. During times of a global health crisis in which

there is a call for social isolation, such as the one we face currently with the COVID-19 pandemic, it is important to find ways to maintain communication and social cohesion to preserve each other's well-being.

NEIGHBORHOOD AND BUILT ENVIRONMENT

Access to Healthy Foods

Food is an essential human need. It plays a major role in an individual's health and quality of life. Consumption of healthy foods is associated with lower risk of chronic health conditions. A healthy diet consists of a myriad of fruit, vegetables, grains, protein-rich foods (seafood, lean meats, poultry, legumes, soy products, eggs, etc.), and fat-free or low-fat dairy. Poor diet and nutrition have been linked to chronic conditions, such as CVD, hypertension, diabetes, and even cancer (36).

The individual components of the neighborhood and built environment domain of SDOH are intertwined and affect one another. There are many barriers to the access of healthy foods. Transportation, another component of the neighborhood and built environment domain, plays a major role in the access to healthy foods. A study from 2012 to 2013 found that on average, the nearest grocery store to households in the U.S. was 2.19 miles (36). This makes it difficult for those without their own vehicles or access to public transportation to make a trip to the grocery store.

Food deserts are neighborhoods that are defined as low income areas with little access to healthy foods by the U.S. Department of Agriculture (USDA) (23). These neighborhoods are more likely to contain fast food restaurants and convenience stores than grocery stores. Fast food restaurants and convenience stores contain options that are of lower quality and more unhealthy foods (higher saturated and *trans*-fat and higher calories). Individuals living in food deserts are more likely to have poor diets and nutrition as a result. Compared to Caucasian neighborhoods, African American and Latino neighborhoods are more likely to contain a higher amount of fast food restaurants and convenience stores. This explains why minority populations are more likely to have negative health outcomes than their racial counterparts. Living in a food desert puts an individual at a higher risk of obesity, which is discussed in another section.

Income also plays a role in access to healthy foods. Studies have shown that low-income families depend on cheap foods that happen to be low in nutrient density. Healthy foods, such as fresh fruits and vegetables, are usually more expensive than processed foods. Those who cannot afford fresh foods opt to the processed foods option, which is unhealthy (36). It is important to recognize food deserts and communities that do not have access to healthy foods, especially during a pandemic, when supplies may be in shortage to begin with. If supplies are in shortage, it will be difficult for those who have limited access to healthy foods or food in general to maintain their diet and nutrition altogether. Individuals will also have to make more trips to grocery stores to obtain groceries, which can put them at risk of acquiring the virus. Minority and low-income populations living in food deserts may face more difficulty accessing healthy foods during the COVID-19 pandemic due to customers overbuying and stocking groceries. This could be more of a problem in areas that are food deserts compared to affluent areas.

Neighborhood/Environmental Conditions

Air quality, water quality, pollution, housing, and access to green space can all be discussed under this section. Health disparities due to neighborhood and environmental conditions can be understood by studying how certain population ends up in certain geographic locations. There is an association between racial minorities and geographic location of their residences. Latinos and African Americans are more likely to live in neighborhoods that have higher exposure to pollution from airborne particles such as chlorine, aluminum, and carbon (37). This is due to the fact that high-poverty neighborhoods in which Latinos and African Americans live are more likely to be located near factories, refineries, and landfills that emit pollutants. For a third of Americans, groundwater was found to be the major source of drinking water. Groundwater near factories, refineries, and landfills tends to be polluted with hazardous wastes (37).

Researchers have suggested that air pollution can make individuals more vulnerable to acquiring COVID-19. They reason that pollution particles are acting as vehicles for the virus, which makes it easier for the virus to be transmitted from person-to-person. Researchers say that air pollution may have worsened the outbreak. This may be due to the fact that air pollution weakens the immune system, which decreases one's ability to fight infections (37). A study recently found that an increase in the size of pollution particles, referred to as $PM_{2.5}$, can have an effect on the spread of COVID-19. The study found that an increase of 1 microgram per cubic meter was associated with an 8% increase in deaths related to COVID-19 (38).

Safety also plays a major role in health. High-poverty neighborhoods are more likely to contain higher rates of crime, which decreases safety of community members. People are more likely to utilize available green space for walking, running, or exercising. Another issue in high-poverty neighborhoods is availability of green space. These neighborhoods are crowded to the point where there is minimal green space available for residents. Social distancing has been the key to flattening the curve and decreasing transmission of COVID-19. In neighborhoods that are crowded, social distancing may not be feasible. This puts individuals living in crowded neighborhoods at a higher risk of becoming ill with the virus, as well as increases the rate of transmission of the virus.

Low-income families tend to live in public housing of poor quality (39). A study found that public housing was found to have several infestations with cockroaches, mice, rats, etc. (40). Mold, lack of air conditioning, and tobacco smoke were also a common find (39). This study also found that 22% of children who lived in public housing were diagnosed with asthma compared to only 7% of those living in single-family homes (40). Low-income families may be at a higher risk of acquiring COVID-19.

EDUCATION

High School Graduation

For most jobs and higher educational degrees, a high school diploma is required (41). Without a high school education and diploma, job opportunities become slim. Lack of or less job opportunities can lead to poverty. Poverty can lead to negative health outcomes as discussed previously. The home and school environment is the major determinants of whether a student will graduate high school. Studies have found that students with parents who are not involved in their education are more likely to drop out of high school. Schools with higher crime rates are more likely to higher dropout rates (41).

Students from low-income households are more likely to attend low quality schools and have less access to educational resources. During the COVID-19 pandemic, schools have had to switch to online education. These children may not have access to computers, or internet. This means that children from high-income families are at an advantage when it comes to learning remotely, while children from low-income families are losing ground. Children with parents who are educated and have obtained higher educational degrees may encourage their children to keep pursuing their academic work (41). Non-educated parents may undervalue education compared to educated parents and downplay the importance of maintaining academic standards for their children. This does not make the educated parents better than the non-educated parents. Rather, it is a matter of being aware of and having experiences of how to navigate situations keeping in mind that education is important regardless of the hardships. Children with non-educated parents may not be getting the support that children with educated parents are getting while having to go to school online during this pandemic. Some children are stimulated to do well in a classroom setting and having to participate in distance learning may impact their academic merit.

Language and Literacy

Individuals with lower levels of education and minorities are more likely to have limited English-speaking skills and lower literacy. Those with language and literacy barriers were noted to have worse health status, chronic health conditions, lack health insurance, and have difficulty following medication directions (42).

The U.S. is home to many who speak a language other than English. A new initiative, called the "COVID-19 Health Literacy Project," started by medical students and physicians at Harvard Medical School, is intended to bridge the language barrier gap. This initiative has translated important COVID-19 information in over 35 languages (43). Languages that information can be translated into include Arabic, Bengali, Chinese, Dutch, Filipino, German, Greek, Gujarati, Japanese, Hindi, and many more. Information about the virus, prevention methods to avoid becoming ill with the virus, and treatment options available are included in the fact sheets. This has made it possible to educate the public even with existing language barriers. Creating awareness of the virus and educating the public about the situation and what precautions to take is an important step toward controlling the spread of the illness.

ECONOMIC STABILITY

Employment

The level of education one obtains is a major determinant of the type of job one has, the income they earn, and benefits such as health insurance, paid sick leave, and parental leave (44). Racial disparities also exist in the workplace. Caucasians are more likely to hold white-collar clerical jobs, while African Americans and minorities are more likely to hold blue-collar service jobs (44). Discrimination in the workplace can lead to stress, anxiety, depression, and negative health outcomes. Individuals who are unemployed are more likely to have stress-related conditions such as CVD, hypertension, and diabetes, which are all risk factors for COVID-19 (44).

The U.S. economic activity has slowed down with stay-at-home and quarantine orders. Many people have lost income by losing their job, having their salary reduced, or being put on unpaid leave (45). Approximately 33.5 million Americans have filed for unemployment aid in the last seven weeks (46). Approximately 61% of Hispanics and 44% of African Americans have reported that they have faced wage or job loss due to the COVID-19 pandemic compared to 38% of Caucasians (47). These percentages have increased from 49, 36, and 29%, respectively, since March (47). Unemployment or job loss means individuals do not have or lose their employer-sponsored health insurance. Congress has allowed uninsured individuals to be tested for COVID-19, however, treatment of the virus is not covered (48).

To address the economic downfall, the President of the United States signed the Coronavirus Aid, Relief, and Economic Security Act (CARES) stimulus bill into legislation on March 27, 2020 (45). The stimulus bill provides a payment of $1,200 for each U.S. citizen or U.S. resident alien with an income of $75,000 or less (49, 50). $500 is added to the $1,200 for each dependent child (45). Though it may seem simple, the criteria that have to be met to receive a stimulus check are numerous and complicated. A schedule for distribution of stimulus checks has not been established. As of now, one stimulus check has been sent out to qualifying individuals (50). The President and Congress have mentioned releasing a second check; however, nothing is set in stone (49–51). One check of $1,200 may not be enough for most families. This could certainly be a hindrance for families to eat healthy foods, as they will have to use the money wisely until either another check will be distributed, or the pandemic comes to an end and people can return to work.

There is a fine line between trying to decrease the spread of COVID-19 and preventing the progression of economic decline. It is evident that social distancing and quarantine methods are helping to flatten the curve, however, at the expense of the country's economic stability. Social distancing was recommended early on by each state's governors, and then a lockdown followed. Two states, Georgia and Idaho, demonstrate the rise in incidence of cases in the months of March and April, a decline toward the end of May, and rise again in the months of June and July (51, 52).

Georgia's governor issued a lockdown on April 3, 2020, and Idaho's governor issued a lockdown on March 25, 2020 (53, 54). During lockdown, non-essential workers were directed to stay at home and only go out to the grocery store or to a pharmacy if needed. Social distancing was to be followed strictly during lockdown. Georgia's lockdown was lifted on April 24, 2020 (55). At the end of April, Georgia saw a slight increase in incidence of cases. By mid-June, the incidence is higher in Georgia than before lockdown was implemented, and it is only increasing. Idaho's governor, on the other hand, issued a lockdown on March 25, 2020 (54). There was a rise in incidence at the beginning of April and then a decline by mid-April. Idaho's lockdown was lifted on April 30, 2020 (56). The incidence was <40 cases in Idaho from mid-April to the beginning of June. Since June 1, 2020, the incidence is on the rise, and it is higher in June and July compared to when lockdown was implemented in March. The incidence of COVID-19 cases overall in the U.S. is shown in **Figure 2** (57). It is evident that incidence is once again on the rise as lockdowns have been lifted across the nation and social distancing is no longer being followed as strictly as during the lockdowns (**Figure 2**). It is understandable that the nation's economy is an important consideration when implementing a lockdown across the nation. We will have to wait and see what the future holds for our nation's economy while we try to eradicate COVID-19.

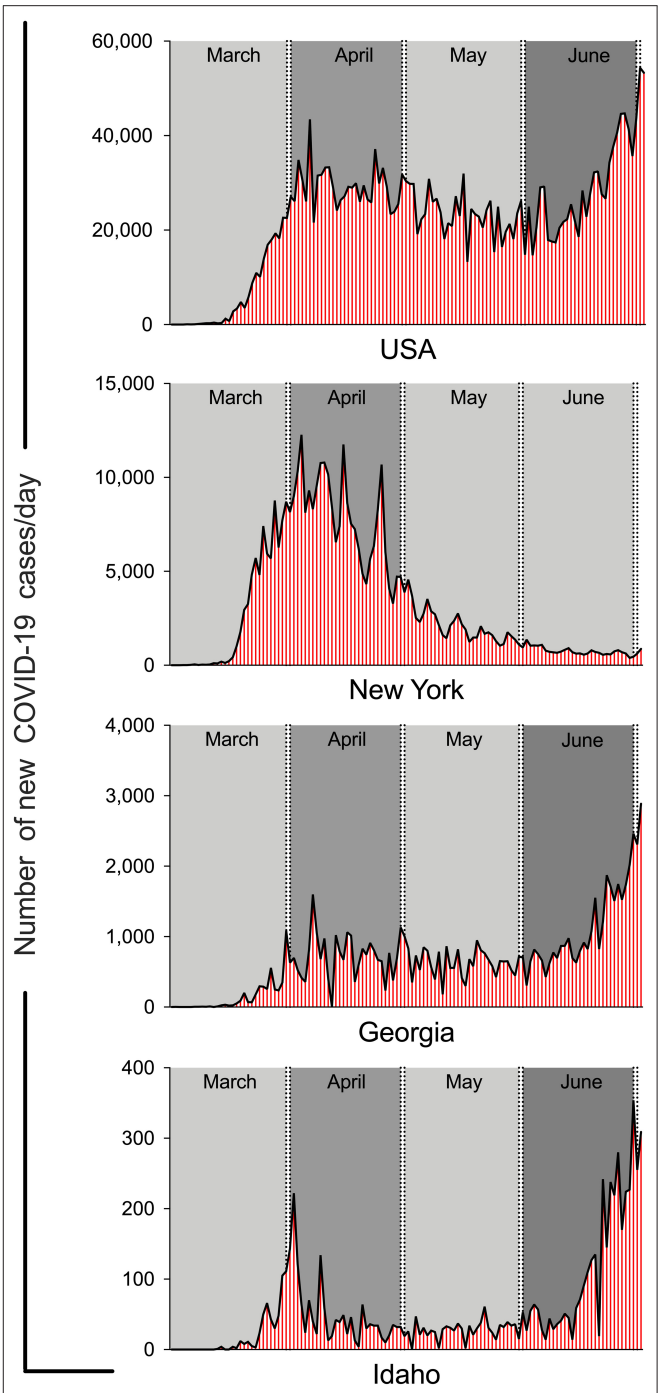

FIGURE 2 | The wax and wane in new cases of COVID-19 per day in USA, New York, Georgia and Idaho. The graphs were generated using the online data form CDC and John Hopkins web sites.

CONCLUSIONS

Pandemics are more of a social problem than a healthcare problem. The population that lives in poverty and in neighborhoods that are overcrowded with poor maintenance and sanitation is being disproportionately affected by COVID-19. It is imperative to provide additional aid for low-income families, such as the stimulus check. This is especially important during times of disease outbreaks, as this is a vulnerable population that is at risk for serious illness. The root cause of being a part of the vulnerable population at risk during outbreaks comes down to income level and racial/ethnic identification. Lower income has been associated with poor dietary intake and habits. Minority groups, such as Latinos, and African Americans are at a disadvantage due to individual and structural discrimination, and they are more likely than their Caucasian counterpart to be vulnerable to negative health outcomes. Therefore, it is evident that the SDOH have been overlooked during this pandemic. Dr. Richard Clarke Cabot, an American physician, was the first in the U.S. to consider socioeconomic, family, and psychological factors when practicing medicine (https://www.ncbi.nlm.nih.gov/books/NBK702/). He observed that there was a correlation between lower socioeconomic status of patients and their probability of succumbing to illness. Historical reports have shown that poverty, inequalities, and SDOH facilitate the spread of infectious diseases. Inequalities in health and healthcare can further add to disparities in morbidity and mortality. Quinn et al. suggested that existing studies of influenza pandemics have not recognized the importance of health inequalities nor have they attempted to analyze differences in socioeconomic factors and how they impact health during times of a health emergency (58). Therefore, it is imperative to respond rapidly and effectively during times of a health emergency. In order to achieve that, it is crucial to be educated about all of the factors that may play a role in health and healthcare before an outbreak of disease even occurs. Having insight into factors that play a role in health

and healthcare, such as SDOH, can facilitate access to medical and non-medical resources to those who are socioeconomically disadvantaged. Public education and creating awareness of the severity of the virus is also important. Awareness of the disadvantaged population that is more vulnerable than the average individual and the rapid spread of COVID-19 should motivate individuals to reduce exposure to others to stop the spread of the disease. The key to fighting an outbreak is to take into account the various factors that play a role in the well-being of a nation. Appropriate and timely education, health care, and social services can be effective measures taken to address outbreaks, such as COVID-19.

Integrating SDOH into efforts to eliminate disparities in health and healthcare can be the solution to reducing disease globally. This can be done through the assembly of an interdisciplinary team that consists of health care professionals, public health professionals, anthropologists, sociologists, researchers, governments, National Institute of Health (NIH), Center for Diseases Control (CDC), World Health Organization (WHO), and others, who can all contribute to analyzing and understanding the various factors that play a role in causing health disparities in populations that already face socioeconomic inequalities. It is also crucial to assess what actions and measures were taken correctly and what went wrong during this pandemic, so that, we will be prepared to handle things in a more efficient manner if any future pandemics arise.

Every person, regardless of where they live, what race they are, and what income they have, should have equal opportunities to stay healthy. By incorporating SDOH into preventing the spread of disease and to approach patient care in a holistic manner, the unfair differences can be minimized socially and economically.

AUTHOR CONTRIBUTIONS

SS designed and drafted/wrote the manuscript. AA referencing and edited the manuscript. KC edited the manuscript. SB designed and edited/wrote the manuscript. All authors contributed to the article and approved the submitted version.

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New Architectural Viewpoint for Enhancing Society's Resilience for Multiple Risks Including Emerging COVID-19

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The spread of COVID-19 all over the world since the beginning of the year 2020 requires a re-thinking of the meaning of the term "resilience" in the field of architecture and architectural engineering. Resilience from the viewpoint of architecture and architectural engineering has been investigated primarily in terms of conventional natural disaster risks (see, for example, Bruneau et al., 2003; Cimellaro et al., 2010; Architectural Institute of Japan [AIJ], 2020a). However, COVID-19 reminds us of the need to investigate resilience also in terms of infection risks. The places where people become infected are principally within buildings and transportation systems. Especially in buildings, three factors considered to be main risks for infection (closed spaces without ventilation, dense gatherings, close connection) often occur. For this reason, the role of architecture and architectural engineering is essential from the viewpoint of reducing the risk of infection, using versatile knowledge and technologies from the fields of architectural and regional planning. Following the appearance of COVID-19, architectural designers and engineers have an important mandate to think about the role of buildings and their related fields.

Keywords: cities and urbanization, COVID-19, infrastructure, local and regional development, manufacturing and production, resilient building, supply chain and transport, sustainability

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Since the beginning of 2020, the COVID-19 virus has spread all over the world, requiring us to re-think the meaning of "resilience" in the fields of architecture and architectural engineering. In architecture and architectural engineering, resilience has traditionally been investigated primarily in terms of conventional natural disaster risks (see, for example, Bruneau et al., 2003; Cimellaro et al., 2010; Architectural Institute of Japan [AIJ], 2020a). COVID-19 reminds us of the need to also investigate resilience in terms of infection, due to the fact that the places where people become infected are principally buildings and transportation systems. At present, the three main factors that increase risk of infection (closed spaces without ventilation, spaces that encourage dense gatherings, and environments that foster close physical connections) often occur in buildings. Versatile knowledge and technologies from the fields of architectural and regional planning could play an essential role in reducing these risks. Following the appearance of COVID-19, architectural designers and engineers have an important mandate to re-think the role of buildings and other related fields.

By focusing on aspects of architecture, it is possible to consider a society of resilience that encompasses health-related risks like COVID-19 alongside conventional natural disaster risk. Aspects of "resisting ability" and "recovering ability" offer a way of classifying factors at multiple scales that might enhance resilience toward both COVID-19 risk and conventional natural disaster risk. These abilities represent the two main constitutive factors of resilience (see **Figure 1** and **Table 1**). Resisting ability describes the process of being able to "plan and absorb" (Linkov and Trump, 2019), and recovering ability corresponds to the process of being able to "recover and adapt" (Linkov and Trump, 2019). These abilities also provide new concepts of multiple scales, factoring in the human scale, building scale, regional scale, and cyber scale, among others. In conventional natural disaster risk the factors related to the human scale are not significant to its experience, but the added dimension of COVID-19 risk reminded us of the importance of taking into account these other factors, illustrated in **Table 1**. This aspect is the original point in this perspective to be focused.

As discussed here, important points in COVID-19 risk are different from those in conventional natural disaster risk. Firstly, at the **human scale** for COVID-19 risk, resisting abilities include the improvement of hand hygiene, wearing masks and faceguards, maintaining social distance, and maintaining strong immunity (through nutrition and exercise). On the other hand, recovering abilities include boosting immunity, digitization of business data, adaptation to DX (digital transformation), and the creation of communication hubs for people from various fields. These resisting and recovering abilities should also be considered for conventional natural disaster risks, except for the maintenance of social distance which drives the three occurrence probabilities (closed spaces, dense gatherings, close connections), which increase the risk of transmitting and contracting COVID-19.

Secondly, at the **building scale** for COVID-19 risk, resisting abilities include ventilation planning to prevent aerosol infections, flow line planning to prevent unnecessary human contact, equipment planning (electricity, water supply, and drainage), and structural engineering planning for building space usage. On the other hand, recovering abilities include the flexibility to make changes to building usage (hotels, rental residences, care facilities), digitization of design data (DX adaptation), promotion of building information modeling (BIM) technology, and shelter planning in maintaining social distance. While the reduction of vulnerabilities in buildings is usually considered to be the main objective for conventional natural disaster risk; the primary focus for COVID-19 risk is the prevention of infection and an increase of flexibility in how buildings are used. This is a new analysis, differentiating between the characteristics of conventional natural disaster risk and COVID-19 risk.

Thirdly, at the **regional scale** for COVID-19 risk, resisting abilities include changes in commuting style (time-lag commuting, flex time), promotion of telework (DX adaptation), avoidance of dense dwellings and workplaces, leading to reduction of concentration. In addition, return to provincial areas (pastoral city planning) could also lead to reduction of concentration, as could the renovation of old houses and buildings for remote working. Furthermore, the planned relocation of hospitals, schools, and city halls, as well as the distributed allocation of the main functions of a company, could also lead to a reduction of concentration. On the other hand,

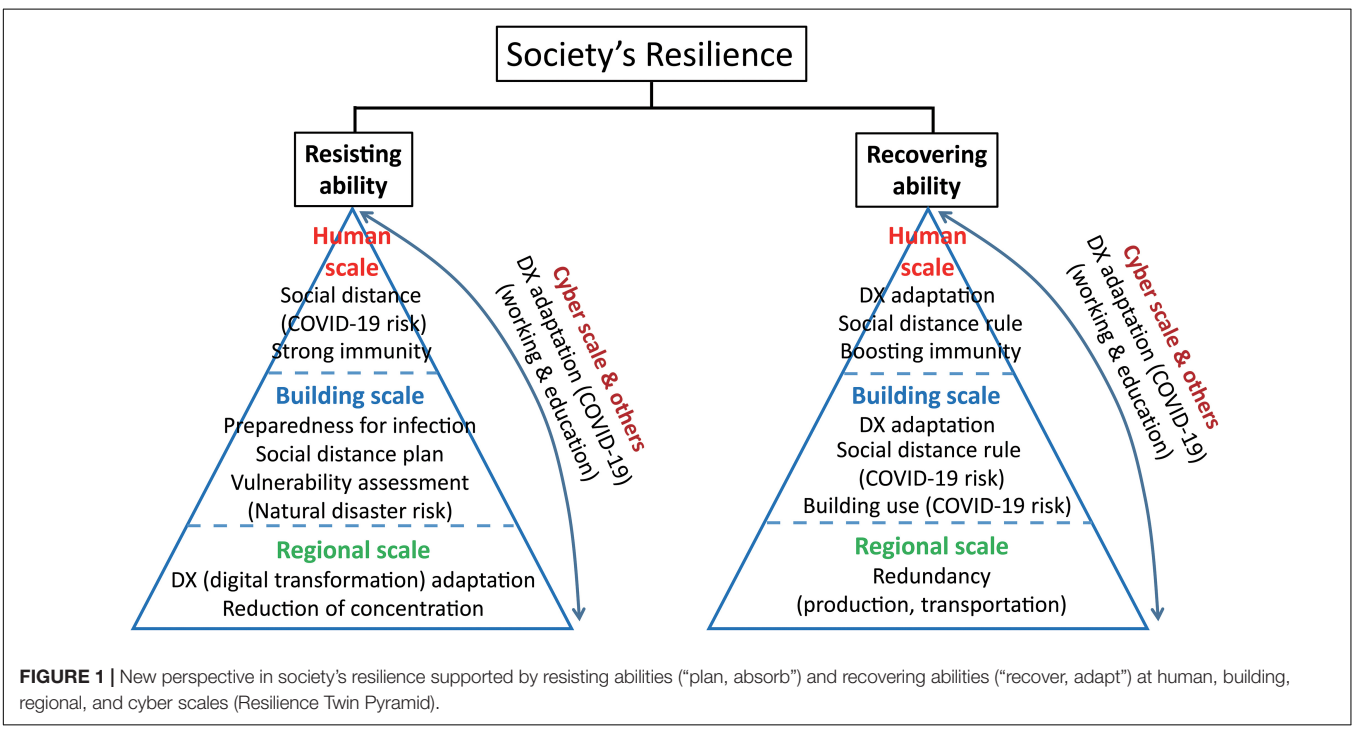

FIGURE 1 | New perspective in society's resilience supported by resisting abilities ("plan, absorb") and recovering abilities ("recover, adapt") at human, building, regional, and cyber scales (Resilience Twin Pyramid).

TABLE 1 | Classification of factors in several scales enhancing resilience for COVID-19 and natural disaster risks.

	COVID-19 risk / Natural disaster risk			
	Human scale	**Building scale**	**Regional scale**	**Cyber scale and others**
Resisting ability ("plan, absorb")	Strengthening of hand hygiene	Ventilation plan	Change of commute style (Time-lag commute, Flex time)	Online ability of working tool and data in company (DX adaptation)
	Wearing of mask and faceguard	Flow line plan (Prevention of unnecessary people's contact)	Promotion of telework (DX adaptation)	Online ability of educational tool (DX adaptation)
	Keep of social distance	Equipment plan (Electricity, water supply and drainage)	Avoidance of dense dwelling and working	Strengthening of global analysis ability of information
	Keep of strong immunity (Food and exercise)	Structural engineering plan	Return to local area (Pastral city plan), Renovation	Advanced use of AI and robotics technologies for architectural design and construction
			Planned location of hospital, school, city hall	
			Distributed allocation of main functions in company	
Recovering ability ("recover, adapt")	Boosting immunity	Flexibility for change of building use (Hotel, rental residence, care facility)	Multiplication of supply chain	Insurance
	Digitization of business data	Digitization of design data (DX adaptation)	Strengthening of domestic production	Keep of internal reserves
	Adaptation to DX (Digital transformation)	Promotion of BIM technology	Strengthening of home delivery service	Online of subsidy from government to company and people
	Construction of communication hub with people in various fields	Shelter plan for keeping social distance	Duplication of transit and transportation	Producing ability of multiple different products
				Strengthening of intelligence network
				Advanced use of AI and robotics technologies for architectural design and re-construction

recovering abilities include the multiplication of supply chains, strengthening of domestic production, strengthening of home delivery services, and duplication of transit and transportation options. For COVID-19 risk, the prevention of infection and the multiplication and increased diversity in social activities are a strong point of focus in differentiating the characteristics of conventional natural disaster risk from those of COVID-19.

Finally, at the **cyber scale and others**, resisting abilities include the online abilities facilitated by working tools and data sets within companies (DX adaptation), and the online ability of educational tools (DX adaptation). Other resisting abilities include the use of advanced technologies such as AI and robotics in architectural design and construction, and as a way of strengthening the global analysis of information. Recovering abilities include insurance contracts, maintenance of internal reserves, subsidies from the government to companies and people, the production capability of multiple different products, advanced use of AI and robotics technologies for architectural design and re-construction, and strengthening intelligence networks. In the past, most natural disasters have occurred locally, making it unnecessary to respond to disasters at a national or global scale. However, nationwide responses, such as DX adaption, are necessary in managing COVID-19 risk. It should be noted that the cyber scale encompasses all human, building, and regional scales (see **Figure 1**).

Several previous studies in the field of resilience science are closely related to this perspective, which factors in health and pandemic related risk. Four domains of resilience (physical, cyber/information, cognitive, and social) were introduced in studies by Linkov et al. (2014, 2018), and Linkov and Trump (2019). Each of these studies define "resilience" as the ability to absorb/respond, recover, and adapt. Linkov et al. (2014) have discussed the concept of resilience from the viewpoint of the relationship between risk and the resilience management, by assessing the resilience of a town facing various risks including those of infection. This study discussed factors related to the

human scale historically, including those effecting the city of Venice during a plague in the fourteenth century. They conclude that better overall system management can be achieved in the face of unknown or unquantifiable threats by integrating risk and resilience management and assessing the system over multiple domains: including the physical, those related to information, the cognitive and the social. Although it was not aimed at the field of architecture, a notion of resilience directly related to COVID-19 was also discussed by Hynes et al. (2020). Similarly, Kurth et al. (2019) have presented a comprehensive review mainly from the viewpoint of conventional natural hazards, except for infection risks. They discuss related notions of functionality, recovery, adaptation, indeterminacy, modeling and uncertainty, regulatory mechanisms, economic challenges, and so forth. It is expected that these notions and ideas will in future be applied to infection risks such as COVID-19.

Over the next 100 years, the fields of architecture and architectural engineering are expected to play an important role in responding to and overcoming infection risks as well as natural disaster risks. Since resilience enhancing factors comprising the human scale, building scale, regional scale, cyber scale, and others have strong and complex correlations, it is necessary to consider systematic challenges and evolve examination of risk in architecture and architectural engineering. In response, the Architectural Institute of Japan launched the COVID-19/HUB (see Architectural Institute of Japan [AIJ], 2020b) in June 2020, a forum on its homepage for institute members to submit useful information. Although it is important to note that cultural circumstances and technologies are different from country to country (and that the perspectives presented here may be affected in this way), the essential points underlying this discussion may be of use.

AUTHOR CONTRIBUTIONS

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With Corona Outbreak: Nature Started Hitting the Reset Button Globally

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Considering the potential threat and the contagious nature of the Covid-19 pandemic, lockdowns have been implemented worldwide to stop the spread of this novel virus. The coronavirus pandemic has hit the world severely, representing the most severe threat to human health in more than a century. The environment from local to global scales has witnessed apparent positive and negative impacts. Global lockdowns have drastically altered the patterns of energy demand and have caused an economic downturn but at the same time, have provided an upside-cleaner global environment. Such immense unintended advantages offer opportunities for unprecedented insights into the dynamics of our natural and built environments that can lead to viable paths for the conservation and perpetuation of the recovered environments and through sensible policies and practices that can help to create new recovery pathways. Knowledge gained from the studies suggests that a substantial relationship exists between the contingency measures and environmental health. Here in this review, the authors discussed the impact of coronavirus pandemic on human life, healthcare organizations, and the environment. The parallels between the Covid-19 and other diseases are mentioned. Finally, the impact of Covid-19 on society and the global environment has also been highlighted.

Keywords: SARS virus, COVID-19, environmental pollution, pandemic, respiratory diseases

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INTRODUCTION

Coronaviruses belong to the group of viruses with subfamily *Coronavirinae* within *Coronaviridae* family and are deemed as possible agents of respiratory diseases with symptoms such as flu, fever, runny nose, cough, breathing difficulty, pneumonia, and lung infection (1). In December 2019, a novel coronavirus disease (Covid-19) originated, in Wuhan, Hubei province, China, and soon sprouted across the globe (2). By February 2020, the daily number of Covid-19 cases outside China had increased drastically, with Italy, USA, Spain, Germany, South Korea, Japan, and Iran being the new major epicenters. Based on the alarming levels of spread and severity, on 11 March 2020, the world health organization (WHO) characterized the Covid-19 situation as a pandemic, and by the end of March 2020, Europe emerged as the new hotspot and was declared as the world's major epicenter (3). As of 14 July, the Covid-19 disease has spread to more than 200 countries and Union Territories (**Figure 2**), with over 13,177,855 confirmed cases and over 574,793 confirmed deaths worldwide (2). As this global pandemic hits more than 200 countries, the virus besides taking a huge toll on public health has completely hijacked the rhythm of our daily lives, hit the global economy, and forced the countries to shut their borders (2, 5). Data released by European Space Agency (ESA)

and National Aeronautics and Space Administration (NASA) indicates that pollution in some of the epicenters of Covid-19 such as Wuhan, USA, Spain, and Italy has decreased by up to 30% (3). With the USA, Spain, Italy, UK, France, and Germany, among the worst-hit countries in terms of infections and deaths, India is also facing the heat, and the figures too are no less devastating. Environmental pollution has its roots in industrialization and urbanization, which are the main sources of the huge release of greenhouse gases (6). The majority of the studies conducted in the recent past have focused more upon fighting against this deadly virus but very few are focused on the indirect beneficial effect of this pandemic on the environment (3, 6, 7). Climate experts predicted that the emission of greenhouse gases (GHGs) could fall by large amounts (nearly 8%) since World War II (8). This reduction in the level of GHGs is a consequence of lockdown and social distancing policies adopted by governments in different countries to combat the coronavirus spread. These lockdown measures severely affect the country's main commercial activities (9). As a result, industrial facilities and power plants stopped their production and uses of vehicles decreased considerably. This led to an intense decline in the concentrations of particulate matter and nitrogen dioxide (NO_2) in China and the reduction of air pollution in Europe. Therefore, in this review, we discussed both direct or indirect positive and negative effects of the Covid-19 pandemic on the environment and human health (**Figure 1**).

CORONA PANDEMIC AND HUMAN LIFE: A GROWING MISERY

The pandemic turn's messier and everyday life suffers, as the world remains under lockdown (9). As mentioned above, till this writing, the number of Covid-19 cases worldwide was 12,977,429, with over 570,259 fatalities (https://coronavirus.jhu.edu/) and over 2.5 billion people around the world under lockdown and stay-at-home orders (2). In the present era, in which we live today, the development is at its peak, with quality and sophistication of the technologies and medicines at their best. Moreover, we are also witnessing a rapid and efficient collaboration and communication of nations at global levels, yet this Covid-19 pandemic is sweeping throughout the globe with high mortality, grounding most of the global population, bringing the healthcare systems of the world's developed countries to a breaking point, and shattered our views of normality and peaceful life (10–12). It is quite enough to say, that the combination of a deadly and rapidly propagating virus and the weak health infrastructures, less information about this virus, and unavailability of vaccine and proper medication, have created the perfect storm and the people are in a panic. Covid-19 pandemic has been an urgent wake-up call for many developed and rich countries, in terms of their failure to stop this pandemic and save the lives of their citizens, as a result, has brought forth their fragile healthcare systems (13). Lack of effective testing, understaffed hospitals, precise and science-oriented guidance and directions, crumbling healthcare systems, and early planning to procure necessary medical equipment [like personal protective equipment (PPE)], despite increasing evidences that the world is facing a global health emergency has been shocking in most of the developed countries especially in the USA, EU, and KU (14). These countries, being superior in terms of their unions, quality and strength of medical experts and researchers, economic strength, and better healthcare systems, failed enormously in dealing with this pandemic (15). This have unfortunately placed the weak and marginalized section of the population at greater risk.

PARALLELS BETWEEN COVID-19 PANDEMIC AND OTHER GLOBAL CRISIS

The present Anthropocene is witnessing an upliftment of global crises such as climate destabilization, population explosion, conflicts, increasing levels of inequality among the people, economic uncertainty, mounting public health threats, and most recently the Covid-19 pandemic (3). All these global crises are slowly tipping the balance, questioning the global economy, financial markets, and public health thereby forcing the society to rethink the next steps. There are certain degrees of parallels that can be drawn between the ongoing Covid-19 pandemic and some other contemporary crises the world is currently facing. All of these necessitate long-term thinking and global response guided by science to address these crises. In this view, the Covid-19 pandemic may provide an opportunity to the scientific community and the political system for a much deeper understanding of the global crises and could help us to tackle the biggest threat of the century, the climate crisis. According to Wyns, a member of the climate change panel at the WHO, the world is witnessing overwhelming consequences of the under-prepared health systems because of these shocks, with most of these having a clear climate change signature. Almost all the health shocks have one thing in common; they hit the poor, vulnerable, and marginalized the hardest (2). At least 50% of the global population does not have the most basic health services, therefore when a disaster hits, global inequality is sustained, and compensated with the lives of the weak and marginalized sectors of the society (11, 13). The same stands true for climate change, e.g., the burning of fossil fuels besides adding to air pollution disproportionately impacts the health of poor and weaker people. Secondly, the Covid-19 pandemic like other global crises has crushed the entire global development with records of economic recession and financial meltdowns. This has put the fate of not only the poor but also the rich countries under such a threat that the world has never seen. With international trade slowing down, commodity prices collapsing, the third-world countries that were already in misery are on the edge of full-blown sovereign debt crises (16).

MEASURES TO SLOW DOWN THE CORONAVIRUS

With the world locked up in a deadly fight against the Covid-19 pandemic, countries across the globe are setting standard measures to slow the spread of this virus. Without enough

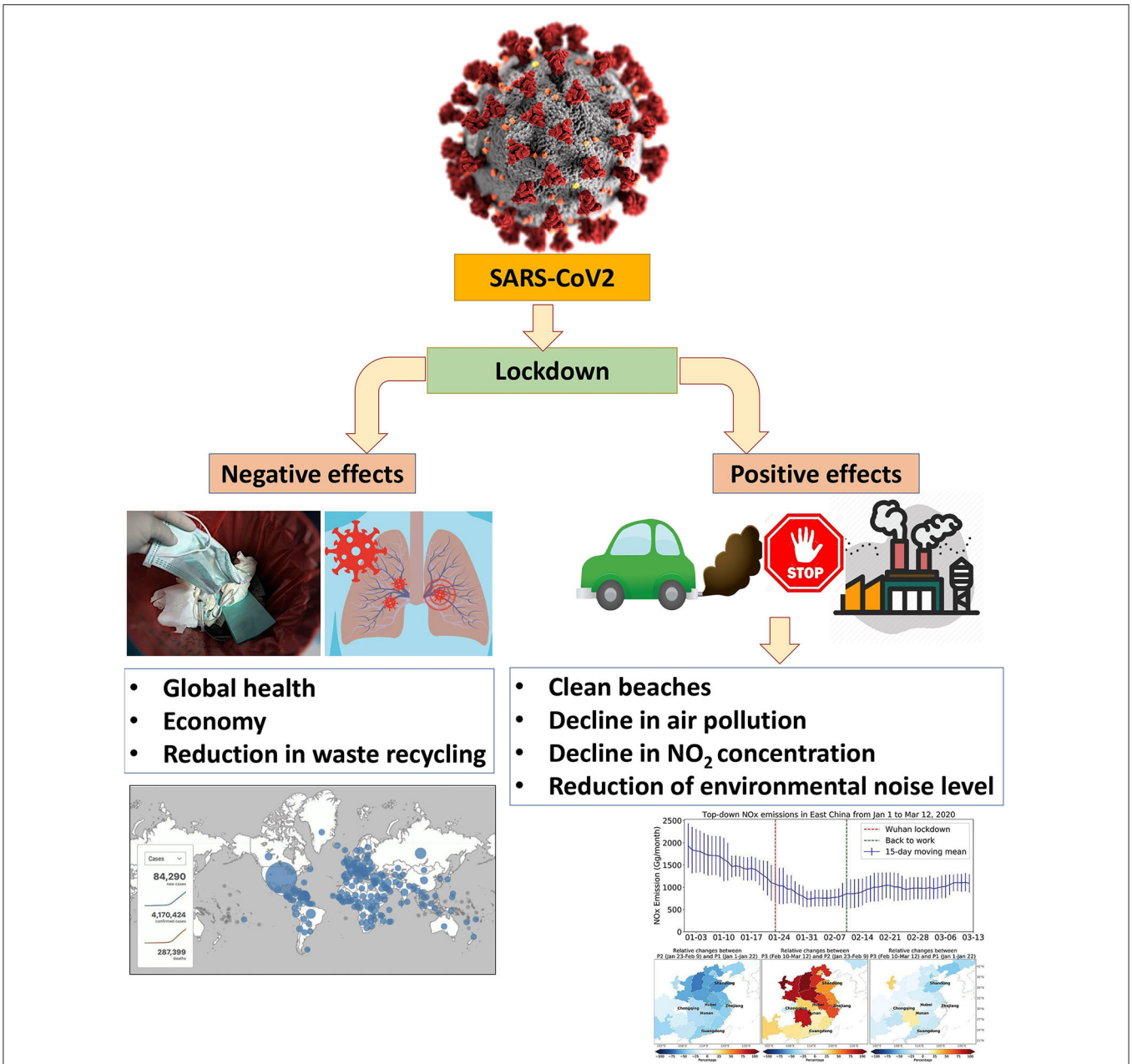

FIGURE 1 | The positive and negative effects of Covid-19.

test kits, the low-income countries are mainly relying on the healthcare workers to trace, quarantine, and self-isolate the people to slow down the rate of infections. In these countries, people only get tested if they develop symptoms (15, 16). Experts predict that the stakes are high enough if the present containment measures fail to slow the spread of this deadly viral outbreak. Some of the main measures taken by the governments to slow down the outbreak are contract tracing, travel restrictions, social distancing, temperature checks, widespread testing, and ban on gathering, closing of educational institutes, lockdowns, and self-quarantine (15).

COVID-19 AND THE GLOBAL CLIMATE CHANGE

Irrespective of the obvious decline in CO_2 emission and air pollution owing to the lockdowns which although temporarily, but may contribute to mitigating climate change (17, 18), many parallels indeed do exist between the challenges in fighting this global climate change and pandemic. As discussed, the mandatory lockdowns have recorded up to a 5°C reduction in temperature than the prelockdown periods, indicating that the industrial sector is likely responsible for the energy footprints that

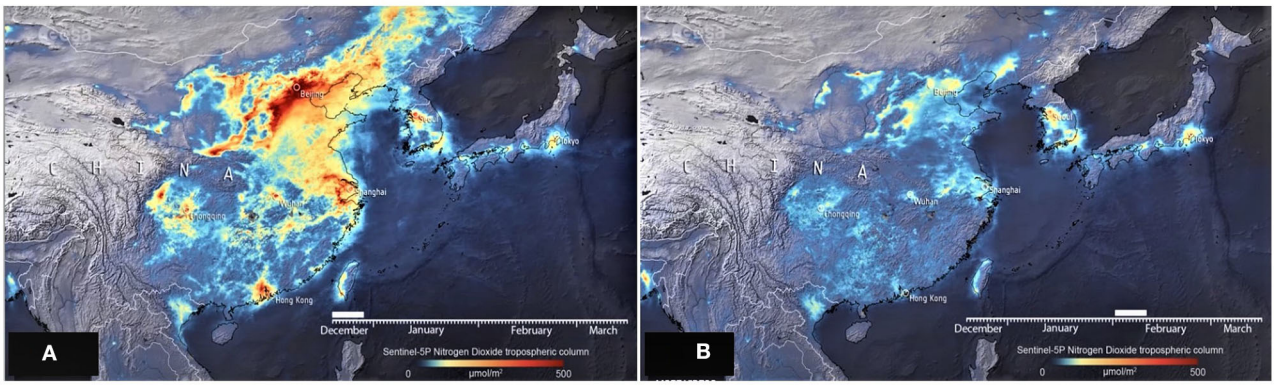

FIGURE 2 | NO_2 drops down in the coronavirus epicenter Wuhan, *Hubei Province*-China. **(A)** In December 2019, **(B)** February 2020 (4).

can dramatically increase the temperature. Since, both climate change and pandemic are existential challenges that the human race is facing. Neither the coronavirus pandemic nor the climate sees the continental borders, as is evident from the current Covid-19, floods in midwest plains, bush fires in Australia, droughts in California, growing deserts in Central Asia, retreating glaciers in the Alps, and the melting polar ice caps, and the consequences of climate change will affect all of us (humans) in some form at some point and no one can escape these consequences (19). Therefore, there is a need to consider all these problems as "our problems" and its urgent time to think and act together. The catastrophic consequences of climate change are quite severe and can damage the environment and biodiversity. However, learning from the lessons of Covid-19, we must act now to avoid any further global catastrophe and be aware of the sinister threats that may arise gradually. Similarly, ignoring the ever-growing scientific evidence of both climate change and the Covid-19 pandemic cannot save us from the hazardous consequences (20, 21). Therefore, the need of the hour is to make decisions based on scientific evidence. Fighting any global disaster needs international collaboration so that scientists can work together and address the challenges. In the case of the present coronavirus pandemic, the global collaboration is impressive, similarly, the modeling and understanding of climate change issues are a global collaborative effort by the Intergovernmental Panel on Climate Change (IPPC) (17).

POSITIVE AND NEGATIVE IMPACTS OF COVID-19

Without a viable therapy and vaccine, the international community is on tenterhooks trying to limit the spread of coronavirus and reduce the mortality from the Covid-19 pandemic. The virus has quickly impacted the government and public health systems and forced the governments to declare a national and international public health emergency. Given the restrictions in public movement, closed borders, reduced public transport, halted non-essential services, and shelter-in-place orders, the planet is witnessing both the positive and negative effects of the Covid-19 pandemic (3).

POSITIVE EFFECTS OF COVID-19 ON THE ENVIRONMENT

The Planet Earth: An Unlikely Beneficiary of Corona Pandemic

With the global lockdown in process, the Internet is abounded with articles and the social media outlets with pictures, showing the planet being the unlikely beneficiary of this Covid-19 pandemic (22). Nature seems to have hit the reset button, reclaiming the spaces to heal itself as the anthropogenic activities have slowed down. Amidst all the gloom and doom that the Covid-19 pandemic is giving, there seems to be a proverbial silver lining and some positive consequences as well (22). Some of these are mentioned below:

Decrease in Air Pollution Level

Air comprises the immediate environment of human beings, which is vital for their survival. With 91% of the global population living in places where the air quality is poor, with Air Quality Index (AQI) exceeding the permissible limits (23), the possible health effects of the degraded air quality had the largest footprints attributable to the pervasive, pernicious, prolonged, and constant exposure to pollution. Although, the possible health effects of pollution in general and air pollution, in particular, are considered the tip of the iceberg, however, the consequences of the global air pollution are manifested in terms of the significant percentage of deaths worldwide each year (24). The Lancet commission reports on pollution and health suggest that pollution accounts for more than 16% of the global deaths, with air pollution alone contributing up to 8% of these deaths, which is three times more than the deaths due to tuberculosis, malaria, and AIDS and 15% more than warfares and other global violence (24, 25). Estimates suggest that more than 90% of the pollution-related deaths occur in developing countries, such as Asia and Africa. The United Nations (UN) General Assembly has already adopted 17

sustainable development goals (SDGs) related to climate change. The UN general assembly has adopted additional SDGs on clean air, clean water, good health, responsible production, and the industrialization of cities, marine, and terrestrial life (24, 25). In response to the current Covid-19 pandemic and with countries suspending transport and millions of people put in lockdown to flatten the curve, global air pollution has significantly come down, with carbon monoxide emission reduced by more than 50%. China was the first country to implement self-quarantine measures and strict traffic restrictions to control the expansion of Covid-19. This global ban on traffic mobility and lockdown greatly limited transportation emissions and declined industrial and residential heating. These actions were found to generate changes, as reported by NASA and ESA. The level of NO_2 was reduced by 12.9 and 22.8 $\mu g/m^3$ in China and Wuhan city in Hubei Province, respectively [(4), **Figure 2**]. Similarly, particulate matter (PM 2.5) was found to reduce by 1.4 $\mu g/m^3$ in Wuhan but showed a significant dropdown (18.9 $\mu g/m^3$) in the majority (more than 350) of the cities. **Figure 3** clearly illustrates a sharp reduction in NO_2 concentrations in other European countries such as Germany, Italy, Spain, and France [(26), **Figure 3**]. The dramatic increase in the air quality level across China during the quarantine period was also detected by the Copernicus Sentinel-5P satellite. Similarly, the data from the Copernicus Sentinel-5P satellite, using the nitrogen dioxide tropospheric column density, revealed a steep decline in air pollution, particularly in the NO_2 emissions, over Italy, post-corona lockdown. Additionally, based on the reports of Copernicus Atmosphere Monitoring Service (CAMS), the European Union observed a significant drop in PM 2.5 (20–30% approx.) in February 2020 compared with the monthly average of 2019, 2018, and 2017 (27, 28) (**Table 1**). According to Fei Liu, an air-quality scientist at NASA's Goddard Space Flight Center, such dramatic dropoff in the air pollution was seen for the first time from January 2020. China also witnessed a significant dropdown (36%) in coal-fired power from 3 February to 1 March 2020 (28). Coronavirus has cut emissions faster than years of climate negotiations. In India, like in the rest of the world, with strict lockdown in place and with a lesser number of people venturing, the country has seen a drastic fall in pollution levels. The AQI lowered from 500 to 600 in winters, to as low as 50 in April (**Figure 4**) (https://www.aqi.in/). In China alone, all the interventions to contain the severe acute respiratory syndrome coronavirus (SARS-CoV)-2 outbreak led to air-quality improvements with prominent health benefits that outnumbered the confirmed Covid-19 deaths (28).

As mentioned, the locking down of cities has significantly improved the environmental quality with a sharp drop in air

TABLE 1 | Reduction in particulate matter (PM 2.5).

Countries	Average PM 2.5 during lockdown 2020 ($\mu g/m^3$)	Reduction compared with 2019 (%)	Reduction compared with prior 4-year average (%)
Los Angeles, USA	5.5	−31	−51
UK	16.2	−9	+6
China	35.1	−44	−50
Italy	16.7	+30	ND
Spain	6.4	−11	+2
New York, US	4.4	−25	−29
Brazil	10.1	−32	−26*
South Korea	24.1	−54	−32
India	32.8	−60	−55

ND, no data.
**data is compared on the basis of a 3-year average rather than a 4-year average. Source, https://www.iqair.com/world-air-quality-ranking.*

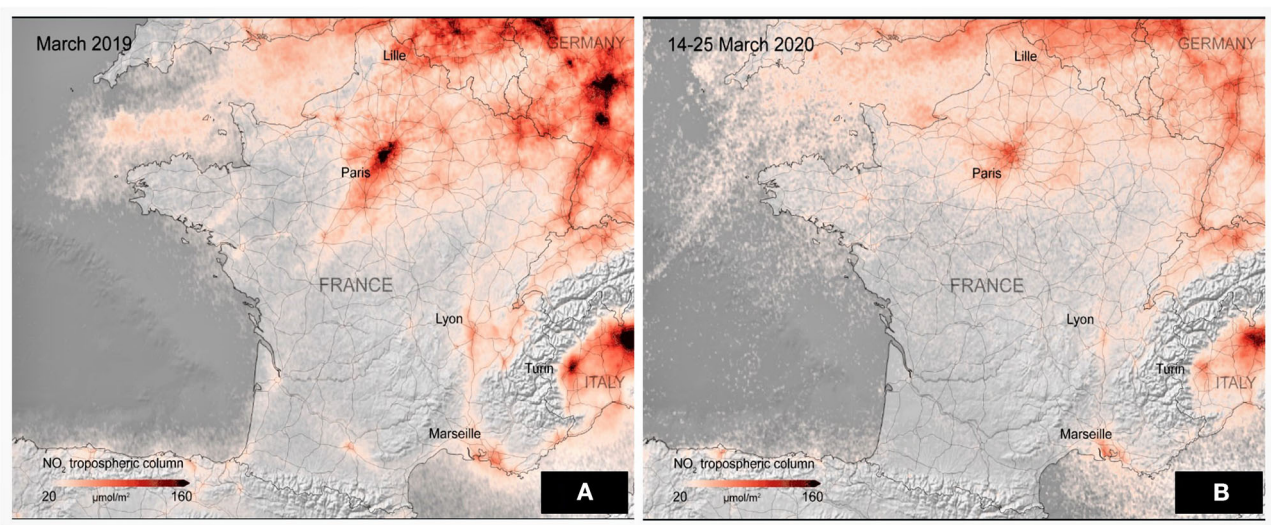

FIGURE 3 | Satellite images from ESA showing a dramatic reduction in the amount of harmful greenhouse gas emissions in the atmosphere. Pollution drops down in European countries amid coronavirus quarantine **(A)** As on March 2019, and **(B)** March 2020 (26).

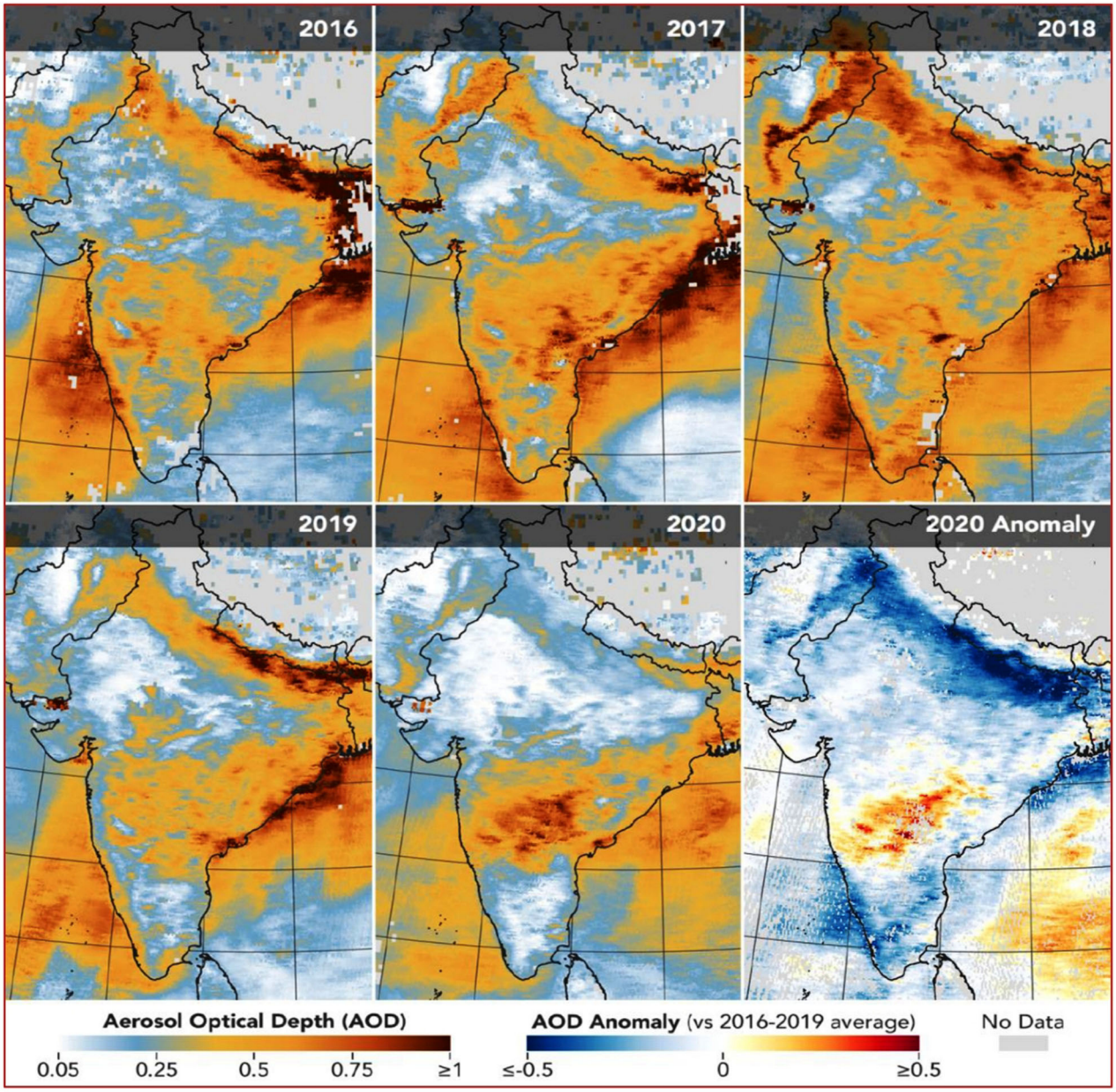

FIGURE 4 | Pre- and post-lockdown level of airborne aerosols over India Source: NASA and ESA, (source, https://earthobservatory.nasa.gov/images/146596/airborne-particle-levels-plummet-in-northern-india, https://earthobservatory.nasa.gov/. accessed date: 13 May 2020).

pollution levels across several countries (2, 6, 29–33). Whereas, before and after lockdown comparison is problematic because it lacks proper counter facts. However, despite a return to normalcy, and easing of restrictions, there is evidence to suggest that the air quality has considerably improved after the lockdown (31). Data analysis from different countries shows low NO_2 pollution levels (30% below the normal level at the end of June) despite traffic and commercial operations being back to normal. Moreover, studies suggest that more developed countries could be more substantially influenced by lockdown, as industrial activities remain largely suspended (16). Similarly, the lockdown effects are larger in rich and cold areas and cities with more traffic volumes experience a more substantial reduction in air pollution because richer countries have higher electricity demands and colder areas have higher coal demands, respectively (29–33). Data like these hint that mother earth is an unintended beneficiary of the Covid-19 pandemic.

Environmental Noise Pollution Reduction

Environmental noise pollution is well-defined as an undesirable sound generated by various anthropogenic, transport, industrial, and commercial activities and is the major source of discomfort for the environment and human health (3, 29). Prolonged exposure to noise pollution has been shown to cause a range of health problems such as stress, tinnitus, cognitive impairment, cardiovascular disease, hearing loss, lack of sleep, fatigue, poor concentration, difficulties in communication, and productivity losses from working places. The worldwide imposition of quarantine measures by governments has confined the people to their homes. This global quarantine has not only decreased the use of private and public transportation but has also led to a significant dropdown in commercial activities (3). All these changes have caused a considerable drop in the noise level in most cities in the world. The reports show that noise reductions have gone deep, with seismologists reporting less seismic noise. For example, in Brussels, the seismic noise caused by anthropogenic activities is reported to be down by 1/3 compared with the prelockdown levels (30, 31). Likewise, the decrease in the use of public and private transport along with other commercial activities has caused a significant fall in the levels of noise pollution. With cruises temporarily being on hold, oceans are more in a state of calm. This calmness and decrease in ocean noise is likely to reduce the stress of aquatic creatures. Though the current reduction seems to be a short-term phenomenon, proper and a long-term strategy is needed to check and maintain the environmental noise level within the WHO's permissible limits. As commented by Eulalia Paris, a noise expert and a leading author at EEA, transport sources and other commercial activities are the main causes of noise pollution. As a result, a significant reduction in noise pollution can only be achieved by a long-term and sustainable strategy on the mobility and transportation systems (32).

Immaculate Beaches

In coastal areas, beaches function as important natural capital assets (2, 3, 5) and provide essential services such as tourism, recreation, sand, land, and source of livelihood to coastal communities (33). Besides providing valuable and intrinsic values, the sandy beaches and dunes are sentinel, shielding the heavy impacts of waves and preventing the furious winds from destroying crops, homes, and other livestock. However, the non-responsible and improper use by people has caused many of the global beaches to present pollution problems (33). These aggregated anthropogenic pollutant impacts are now destabilizing and damaging the potential ability of the beaches and other marine environments to provide key ecosystem services such as coastal livelihood and economic stability, global climate stability, and biological integrity (33). With the global states undergoing lockdown and the WHO declaring emergency and social distancing measures to combat the novel coronavirus pandemic, tourism around the world beaches has been affected. Moreover, the complete closure of various industrial activities has almost halted the pollution from these sources. All these unintended measures have caused a remarkable change in the appearance of many beaches in the world. Prominent examples are the beaches of Salinas (Ecuador), Barcelona (Spain), and Acapulco (Mexico), all these beaches now look cleaner and with clear waters (2). Similarly, Mandal et al. (30) and Saadat et al. (34) while studying the effect of Covid-19 lockdown on the surface water quality, found that the water quality of Vembanad Lake, Kerala, increased significantly. The authors also in their study noticed a significant decrease (34%) in the suspended particulate matter (SPM) concentration of the lake water during the lockdown period. All these studies suggest that the virus crisis has brought with it the unintended benefits for the environment and mankind (16).

Animals on Street

The environmental changes brought by the coronavirus were first visible from space. Then, as the disease and the lockdown spread, they could be sensed in the sky above our heads, the air in our lungs, and even the ground below our feet. While humans are restricted to their homes under global lockdown, the wild animals all over the planet seem to have come to reclaim their territory. The media outlets are tweeting and uploading several images and videos showing animals on the streets (3). The emergence of wild animals in urban areas is mostly because there is peace and calm, which attracts these animals to the residential areas (accessible at https://climaterealityproject.org/blog/air-pollution-and-coronavirus-connection-explained).

Feathers Flock Together

While the home confinement rules/lockdown and social distancing have stopped the movement of peoples outside, at the same time, this global lockdown has allowed birds and wildlife to flourish and enjoy all the freedom of nature. Reports confirm that a growing flock of thousands of flamingos beating their black and pink-lined wings has been seen splashing over the glistening water of Nartan Lagoon, of the Adriatic coast. According to park authorities, since January 2020, the number of these birds has been found to increase by 3-fold up to some 3,000. Similarly, the wildlife seems to have regained all their absolute rights and is enjoying the freedom of nature (Agence France–Presse). Similar cases were found in the Indian beaches with flocks of flamingos flying to these beaches with the number increasing by more than 25% compared with previous years.

NEGATIVE EFFECTS OF COVID-19 ON THE ENVIRONMENT

Covid-19 and the Global Economy

Although the territorial colonization ended long ago, this existing global health crisis can serve as a reminder that the colonization of economics, medicine, and politics are still alive. In addition to its immediate effects on the lives and health outcomes, it is now clear that the coronavirus outbreak is likely to have long-lasting effects on the global economy (35, 36). Loss of lives by any sort of pandemic causes irretrievable damage to the society; however, the Covid-19 pandemic apart from taking a huge toll on the global lives has severely demobilized the global economy. To limit further transmission, governments at local, regional, national, and global levels have decided to undergo complete

lockdown. Owing to the complete lockdown and cross-border closure, all the flights, railway services, trucks, buses, and all other types of vehicular transports are suspended. Nearly all the Covid-19-traumatized nations, industries, and entire commercial, educational, religious, and sports institutions are closed. All these restrictions are negatively affecting global economies. Moreover, increased prices, lost income, and overburdened social safety nets will further push the more vulnerable groups into poverty and increase the financial barriers (37). With the production level gone down, the economy of many so-called powerful countries is facing the threat of high inflation. Especially, the gross domestic product (GDP) projections have already been revised downwards in most of the developed countries amid the disruption in production. Most business sectors especially those in tourism, aviation, and hospitality industries are facing serious challenges with a real threat of significant declines in insolvencies, revenue, and job losses (38, 39).

Effect of Covid-19 on Energy Resources

In the global energy systems, coal stands one of the major fuels accounting for up to 40% of the electricity generation (https://www.iea.org/reports/coal-2019). The global coal production was estimated to have increased by 2.7% in 2018 with the annual production of 8.1 billion tons in 2019. The increase was mainly driven by three major coal-producing countries such as China, India, and Australia, which together accounts for 70% of global production. Owing to the coronavirus lockdown, the global output is expected to increase by 0.5% in 2020. However, due to continuing lockdown and other government policies during the on-going Covid-19 pandemic, the global coal market is likely to fall from $816.5 billion in 2019 to $722.8 billion in 2020. This significant decline in the global output is mainly because of the economic slowdown across the countries caused by the global lockdown to stem the spreading of the Covid-19 pandemic. Similarly, the global oil demand was strongly hit, showing a decline (5%) in the first quarter of 2020. This drastic reduction was mainly because of the curtailments in mobility and aviation which alone accounts for more than 60% of the global oil demand. Likewise, the electricity demand has also shown a significant reduction (>20%) due to lockdown measures, with knock-on effects on the power mix.

Impacts on Biodiversity

Although affecting all the sectors of human life, the Covid-19 pandemic propagates exponentially and impacts other global resources at an accelerating pace. This global pandemic has its root deep on how we interact, perceive, manage, and conserve global biodiversity. Reports suggest that there is reduced human pressure on natural ecosystems and wildlife (29). The protected areas have witnessed a significant decline in the number of visitors, caused mainly by the travel ban and park closure, reducing the stress on the wildlife. Besides some of the positive effects (all though temporary), it is quite unclear how the conservation biology will fare in the pandemic aftermath. At present, most of the protected areas appear to be safe, and, biodiversity seems to be benefitting from the reduced human activities; however, threats persist especially in the areas where the enforcement has weakened. Although greenhouse gas emissions, environmental pollution, and many other anthropogenic impacts on the wild nature will ricochet, the support and funding for conservation purposes have to compete with a wide range of priorities for financial resources. The forest sector without any doubt is the main contributor to the development of society and for social and economic recovery in the aftermath of any crisis (29). Forests by-products function as essential sources and support the livelihood during the crisis, by delivering necessary products, such as hygiene and sanitary items, respirator papers, ethanol for sanitizer, biomass for heating, and papers for parcel packaging. The negative effects of the Covid-19 pandemic on production and trade of forest and forest by-products will put many of the key livelihoods and industrial sectors at risk (29, 39). Moreover, the forest sector has high rural to urban migration; however, the Covid-19 pandemic is leading to reverse migration, which has the potential to spread the disease to the remote, distant, and unprepared areas. Furthermore, the effect of this global pandemic on forest-based industries will have instant consequences for forest owners and traders arising primarily from the persistent decline in product runoff and sales (European Family Forestry—sustainability in action) (40).

Other Effects of Covid-19 on the Environment

Since the dawn of civilization, human beings have gradually started manipulating nature for their benefit. Secondly, to satisfy the demands for the ever-growing population, urbanization, and industrialization became quite inevitable and the obvious significance was proved to be detrimental to the global environment (41). Since the outbreak of this novel viral pneumonia, changes to daily life have been swift and unprecedented. As the cases surge and the death toll escalates, both the humans and the environment suffer a lot. Besides the abovementioned ill effects of the Covid-19 outbreak, water bodies and natural and built environments have also experienced significant impacts. For example, to prevent the transmission of coronavirus through wastewater, China has directed the wastewater treatment plants to strengthen the disinfection routines. In contrast, the excessive use of chlorine to treat the water could generate harmful effects on human health (42). Anecdotal evidence indicates that quarantine policies have increased the demands for home delivery, thereby increasing the organic waste production generated by households. Similarly, the increased consumption of medical stuff such as diagnostic supplies, disinfectants, ventilators, N95, and PPE kits, has significantly increased putting the medical waste on the rise; for example, during the coronavirus outbreak, the hospitals in Wuhan China were found to generate an average of 240 metric tons of medical waste per day compared with their previous average of fewer than 50 tons (42). Similarly, in the USA, an increase in garbage production from personal protective equipment has been recorded. The problem got worse, after many countries particularly the USA and the European nations have stopped waste recycling programs in some of their cities,

concerning the risk of Covid-19 spreading in the recycling centers (3). Lastly, the impacts of this pandemic on the behavior and psychological well-being are evident. It is well-known that the calamities and other disasters, particularly the ones related to infectious diseases often elicit the waves of heightened fear and anxiety, thus causing massive disruptions to the behavior and psychological well-being of the people. The same is being seen with this virulent creature. Recent studies have shown that the people whether susceptible or not, are developing severe psychological conditions including depression (50.7%), anxiety (44.7%), and insomnia [sleeping disorder (36.1%)] due to lockdown (39, 41).

Covid-19 Pandemic and the Mental Health

Deadly and disruptive as it already is, the terrible and rapid propagation of Covid-19 pandemic has already induced a considerable degree of concern, worry, and fear among the population in general and certain groups such as care providers, older adults, and people with underlying health conditions in particular. With uncertain prognosis, looming scarcity of medical resources, growing financial losses, the imposition of unfamiliar public health measures that infringe on personal freedoms, and conflicting messages on social media are the major stressors that certainly will contribute to the widespread emotional distress and psychiatric illnesses (43, 44). As mentioned, the public health emergencies have negative effects on the safety, health, and well-being of both individuals and communities. The possible effects on the individuals include stigma, insecurity, confusion, and emotional isolation, while those on the community level include inadequate medical responses due to resource shortage, economic loss, and deficient distribution of necessities, work, and closure of educational institutes (44). All these effects may lead to a range of emotional reactions, unhealthy behaviors, and non-compliance with the public health directives in the population. This is interesting to mention that the previous SARS-CoV-1 epidemics had shown psychiatric symptoms, months after the epidemic was controlled. These indications suggest the possible mental symptoms after SARS-CoV-2 are expected (41). Although the current evidence regarding the direct effect of the Covid-19 pandemic on mental health is scarce, few studies, however, have been carried out indicating that the pandemic has a direct effect on mental health. These authors, while studying the effect of a pandemic on mental health confirmed that the same is affected in the post-pandemic era (43–45). In the population, healthcare workers are regarded as a highly exposed group with a much higher risk of psychiatric symptoms. Although, the number of risk factors of mental health reported is already well-known. Examples of such mental risk factors include present or past medical history, poor self-related health, and female gender. However, the Covid-19 pandemic has added the aspects of self-isolation and quarantine, an established risk factor with psychological impact (46, 47).

CONCLUSION

Like the previous catastrophes on the planet Earth, the humans will win over this pandemic in due course of time; however, people should know the limits to which they can thrust nature before it is too late. Environmental changes are arguably the most vital and severe challenge of the twenty-first century. Despite the continuous efforts by governmental and non-governmental organizations to restore and repair nature, humans can only move a few steps forward and yet there are enormous challenges. However, being a blessing in disguise, the Covid-19 pandemic during the past few months has successfully recovered the environment to a much larger extent and has improved the mutually effective link between nature and humans. While at the same time the lockdown and social distancing have contributed positively toward the environment, though, it is essential to take into account the negative effects such as mortality, impacts on social aspects, and the dramatic economic effects as well. The viral pandemic has produced both positive and negative indirect effects on the environment. At present, it is important to control the disease, reduce the transmission, and proactively save lives. Although the positive impacts on the environment may be temporary, the governmental, non-governmental organizations, and the individuals should learn from this lockdown on how to reduce and minimize the pollution on a long-term basis.

AUTHOR CONTRIBUTIONS

All authors listed have made a substantial, direct and intellectual contribution to the work, and approved it for publication.

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Unemployment, Employability and COVID19: How the Global Socioeconomic Shock Challenged Negative Perceptions Toward the Less Fortunate in the Australian Context

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Unemployed benefit recipients are stigmatized and generally perceived negatively in terms of their personality characteristics and employability. The COVID19 economic shock led to rapid public policy responses across the globe to lessen the impact of mass unemployment, potentially shifting community perceptions of individuals who are out of work and rely on government income support. We used a repeated cross-sections design to study change in stigma tied to unemployment and benefit receipt in a pre-existing pre-COVID19 sample (n = 260) and a sample collected during COVID19 pandemic (n = 670) by using a vignette-based experiment. Participants rated attributes of characters who were described as being employed, working poor, unemployed or receiving unemployment benefits. The results show that compared to employed characters, unemployed characters were rated substantially less favorably at both time points on their employability and personality traits. The difference in perceptions of the employed and unemployed was, however, attenuated during COVID19 with benefit recipients perceived as more employable and more Conscientious than pre-pandemic. These results add to knowledge about the determinants of welfare stigma highlighting the impact of the global economic and health crisis on perception of others.

Keywords: COVID19, employability, personality, Big Five, public policy, unemployment

INTRODUCTION

The onset of COVID19 pandemic saw unemployment climb to the highest rate since the Great Depression in many regions globally[1]. Over just one month, from March to April 2020 unemployment rate in the United States increased from 4.4% to over 14.7% and in Australia the effective rate of unemployment increased from 5.4 to 11.7% (Australian Bureau of Statistics, 2020)[2].

[1]https://fred.stlouisfed.org/series/UNRATE

[2]The Australian figure includes individuals working zero hours who had "no work, not enough work available or were stood down." The US Bureau of Labor Statistics noted that some people on temporary layoff were not classified as such and the unemployment rate could have been almost 5 percentage points higher.

In Australia, a number of economic responses were rapidly introduced including a wage subsidy scheme (Jobkeeper) to enable employees to keep their employees connected to the workforce, one-off payments to many welfare recipients, and a doubling of the usual rate of the unemployment benefits (Jobseeker payment) through a new Coronavirus supplement payment. At the time of writing in July 2020, many countries, including Australia remain in the depths of a health and economic crisis.

A rich research literature from a range of disciplines has documented the pervasive negative community views toward those who are unemployed and receiving unemployment benefits, with the extent of this "welfare stigma" being particularly pronounced in countries with highly targeted benefit systems such as the United States and Australia (Fiske et al., 2002; Baumberg, 2012; Contini and Richiardi, 2012; Schofield and Butterworth, 2015). The stigma and potential discrimination associated with unemployment and benefit receipt are known to have negative impacts on health, employability and equality (for meta-analyses, see Shahidi et al., 2016). In addition, the receipt of unemployment benefits co-occurs with other stigmatized characteristics such as poverty and unemployment (Schofield and Butterworth, 2018a). The changing context related to the COVID19 crisis provides a novel opportunity to better understand the determinants of stigmatizing perceptions of unemployment and benefit receipt.

Negative community attitudes and perceptions of benefit recipients are commonly explained by the concept of "deservingness" (van Oorschot and Roosma, 2017). The unemployed are typically seen as less deserving of government support than other groups because they are more likely to be seen as responsible for their own plight, ungrateful for support, not in genuine need (Petersen et al., 2011; van Oorschot and Roosma, 2017), and lacking reciprocity (i.e., seen as taking more than they have given – or will give – back to society; van Oorschot, 2000; Larsen, 2008; Petersen et al., 2011; Aarøe and Petersen, 2014). Given the economic shock associated with COVID19, unemployment and reliance on income support are less likely to seen as an outcome within the individuals control and may therefore amplify perceptions of deservingness. Prior work has shown that experimentally manipulating perceived control over circumstances does indeed change negative stereotypes (Aarøe and Petersen, 2014).

A number of experimental paradigms have been used to investigate perceptions of "welfare recipients" and the "unemployed." The stereotype content model (SCM; Fiske et al., 2002), for example, represents the stereotypes of social groups on two dimensions: warmth, relating to being friendly and well–intentioned (rather than ill–intentioned); and competence, relating to one's capacity to pursue intentions (Fiske et al., 2002). Using this model, the "unemployed" have been evaluated as low in warmth and competence across a variety of welfare regime types (Fiske et al., 2002; Bye et al., 2014). The structure of stereotypes has also been studied using the Big Five personality dimensions (Schofield and Butterworth, 2018b; Schofield et al., 2019): Openness, Conscientiousness, Extraversion, Agreeableness, and Emotional Stability (for background on the Big Five see: Goldberg, 1993; Hogan et al., 1996; Saucier and Goldberg, 1996; McCrae and Terracciano, 2005; Srivastava, 2010; Chan et al., 2012; Löckenhoff et al., 2014). There are parallels between the Big Five and the SCM: warmth relating to the dimension of Agreeableness, and competence relating to Conscientiousness (Digman, 1997; Ward et al., 2006; Cuddy et al., 2008; Abele et al., 2016) and these constructs have been found to predict employability and career success (Barrick et al., 2001; Cuesta and Budría, 2017). Warmth and agreeableness have also been linked to the welfare-specific characteristics of deservingness (Aarøe and Petersen, 2014).

The term "employability" has been previously defined as a set of achievements, skills and personal attributes that make a person more likely to gain employment and leading to success in their chosen career pathway (Pegg et al., 2012; O'Leary, 2017, 2019). While there are few studies examining perceptions of others, perceptions of one's own employability have been recently studied in university students, jobseekers (Atitsogbe et al., 2019) and currently employed workers (Plomp et al., 2019; Yeves et al., 2019), consistently showing higher levels of perceived employability being linked to personal and job-related wellbeing as well as career success. Examining other's perceptions of employability may be more relevant to understand factors impacting on actual employment outcomes. A majority of studies examining other's perceptions of employability have focused on job specific skills study (Lowden et al., 2011; Dhiman, 2012; Saad and Majid, 2014).

Building on this previous work, our own research has focused on the effects of unemployment by drawing on frameworks of Big Five, SCM and employability in pre-COVID19 samples (Schofield and Butterworth, 2018b; Schofield et al., 2019). Our studies consistently show that unemployed individuals receiving government payments are perceived as less employable (poorer "quality" workers and less desirable for employment) and less Conscientious. We found similar but weaker pattern related to Agreeableness, Emotional Stability, and the extent that a person is perceived as "uniquely human" (Schofield et al., 2019). Further, we found that vignette characters described as currently employed but with a history of welfare receipt were indistinguishable from those described as employed and with no reference to benefit receipt (Schofield et al., 2019). Findings such as this provide experimental evidence that welfare stigma is malleable and can be challenged by information inconsistent with negative stereotype (Schofield and Butterworth, 2018b; Schofield et al., 2019; see also Petersen et al., 2011).

The broad aim of the current study was to extend this previous work by examining the impact of COVID19 on person perceptions tied to employment and benefit recipient status. It repeats a pre-COVID19 study of an Australian general population sample in the COVID19 context, drawing on the same sampling frame, materials and study design to maximize comparability. The study design recognizes that the negative perceptions of benefit recipients may reflect a combination of difference sources of stigma: poverty, lack of work, and benefit receipt. Therefore, the original study used four different conditions to seek to differentiate these different sources: (1) *Employed*; (2) *Working poor*; (3) *Unemployed*; and

(4) *Unemployed benefit recipient*. Finally, for the COVID19 sample we added a novel fifth condition: (5) *Unemployment benefit recipient also receiving the "Coronavirus" supplement*. We except that the reference to a payment specifically applicable to the COVID19 context may lead to more favorable perceptions (more deserving) than the other unemployed and benefit receipt characters.

The study capitalizes on a major exogenous event, the COVID19 crisis, which we hypothesize will alter perceptions of deservingness by fundamentally challenging social identities and perceptions of one's own vulnerability to unemployment. The study tests three hypotheses, and in doing so makes an important empirical and theoretical contribution to understanding how deservingness influences person perception, and understanding of the potential "real world" barriers experienced by people seeking employment in the COVID19 context.

Hypothesis 1

The pre-COVID19 assessment uses a subset of data from a pre-registered study, but this reuse of the data was not preregistered[3]. We hypothesize that, at Time 1 (pre-COVID19 assessment) we will find that employed characters will be rated more favorably than characters described as unemployed and receiving unemployment benefits, particularly on dimensions of Conscientiousness, Worker and Boss suitability. Moreover, we expect a gradient in perceptions across the four experimental conditions, from employed to working poor, to unemployed to unemployed receiving benefits and to show a similar trend for the other outcome measures included in the study.

Hypothesis 2

We hypothesize that the character in the unemployed condition(s) would be rated less negatively relative to the employed condition(s) at Time 2, compared to Time 1. We predict a two-way interaction between time and condition for the key measures (Conscientiousness, Worker and Boss suitability) and a similar trend on other outcomes.

Hypothesis 3

We expect that explicit reference to the unemployed benefit character receiving the "Coronavirus supplement" payment will increase the salience of the COVID19 context and lead to more positive ratings of this character relative to the standard unemployed benefit condition in the pre-COVID19 and COVID19 occasions.

MATERIALS AND METHODS

Participants

Two general population samples (pre-COVID19 and COVID19) were recruited from the same source: The Australian Online Research Unit (ORU) panel. The ORU is an online survey platform that provides access to a cohort of members of the general public who are interested in contributing to research. The ORU randomly selects potential participants who meet study eligibility criteria, and provides the participant with an incentive for their participation. The sample for the Time 1 (pre-COVID19) occasion was part of a larger study (768 participants) collected in November 2018. From this initial dataset, we were able to use data from 260 (50.1% female, *M* Age = 42.1 [16.7] years, range: 18–82) participants who were presented with the one vignette scenario that we could replicate at the time of the social restrictions applicable in the COVID19 context (i.e., the vignette character was not described as going out and visiting friends, as these behaviors were illegal at Time 2). The sample for Time 2 (COVID19) was collected in May–June 2020, at the height of the lock down measures in Australia and included 670 participants (40.5% female, *M* Age = 51.0 [15.8] years, range: 18–85). The two samples were broadly similar (see below), though the proportion of male participants at Time 2 was greater than at Time 1.

Sampling

The pre-COVID assessment at Time 1 was restricted to those participants who completed the social-distancing consistent vignette in the first place to avoid potential order/context effects. This provided, on average, 65 respondents in each of the four experimental conditions. Using the results from our previous published studies as indicators of effect size (Schofield and Butterworth, 2018b; Schofield et al., 2019). Monte Carlo simulation was used to identify the Time 2 sample size that would provide 90% power to detect an interaction effect that represented a 50% decline in the difference between the two employment and two unemployment conditions on the three-key measures at the COVID occasion relative to the pre-COVID difference. This sample size of 135 per condition also provided between 60 and 90% power to detect a difference of a similar magnitude between the employed and unemployment benefit conditions across the two measurement occasions. Given previous evidence that the differences between employed and unemployed/welfare conditions is robust and large for Conscientiousness and Worker suitability (Schofield and Butterworth, 2018b), the current study is also adequately powered to detect the most replicable effects of unemployment and welfare on perceptions of a person's character (even in the absence of the hypothesized interaction effect).

Materials and Procedure

The procedures were identical on both study occasions. Participants read a brief vignette that described a fictional character, and then rated the character on measures reflecting personality dimensions, their suitability as a worker or boss, morality, warmth, and competence, and the participant's beliefs the character should feel guilt and shame, or feel angry and disgusted. At Time 1 (pre-COVID19 context) participants then repeated this process with a second vignette, but we do not consider data from the second vignette.

Manipulation

The key experimental conditions were operationalized by a single sentence embedded within the vignette that was randomly allocated to different participants (employed: "S/he is currently

[3]https://osf.io/wknb6

working as a sales assistant in a large department store"; working poor: "S/he is currently working as a sales assistant, on a minimum-wage, in a large department store"; unemployed: "S/he is currently unemployed"; and receipt of unemployment benefits: "S/he is currently unemployed, and is receiving government benefits due to his/her unemployment"). The four experimental conditions were identical at both time points. At Time 2, an additional COVID19-specific condition was included (to maximize the salience of the COVID19 context): "S/he is currently unemployed and is receiving government benefits, including the Coronavirus supplement, due to his/her unemployment."

All three study conditions will imply poverty/low income. In Australia, few minimum-wage jobs are supplemented by tips, and so a minimum-wage job indicates a level of relative poverty. A full-time worker in a minimum wage job is in the bottom quartile of income earners (Australian Bureau of Statistics, 2017). Prior to the COVID19 crisis and the increase in payment level, a single person with no dependents receiving unemployment benefits received approximately 75% of the minimum-wage in cash assistance. During COVID19 and at the time of the data collection, the rate of pay exceeds the minimum-wage.

Several characteristics of the vignette character, including age and relationship status, were balanced across study participants. Age was specified as either 27 or 35 years, relationship status was either "single" or "lives with his/her partner." The character's gender was also varied and names were stereotypically White.

Design

For Time 1, manipulated characteristics yielded 32 unique vignettes, comprised of four key experimental conditions (employed, working poor, unemployed, and unemployment benefits) × 2 ages × 2 genders × 2 relationship statuses. For Time 2, manipulated characteristics yielded 40 unique vignettes, comprised of five key experimental conditions (employed, working poor, unemployed, unemployment benefits, and unemployed + coronavirus supplement) × 2 ages × 2 genders × 2 relationship statuses. The *vignette template* construction is presented in **Figure 1** including each component of the vignette that was randomly varied.

Comprehension Checks

In both studies, participants were required to affirm consent after debriefing or had their data deleted. Participant comprehension of the vignettes was checked via three free-response comprehension questions about the character's age and weekend activities. Participants who did not answer any questions correctly were not able to continue the study.

Outcome Measures

Personality, employability (suitability as a worker or boss), communion and agency, cognitive and emotional moral judgments, and dehumanization were included as the study outcomes. While not all personality or character dimension measures can be considered as negative or positive, higher scores were used in the study to indicate more "favorable" perceptions by the participants of the characters.

Personality

The Ten Item Personality Inventory was used to measure the Big Five (Gosling et al., 2003) and adapted to other–oriented wording (i.e., "I felt like the person in the story was. . .") (Schofield et al., 2019). Two items measured each trait via two

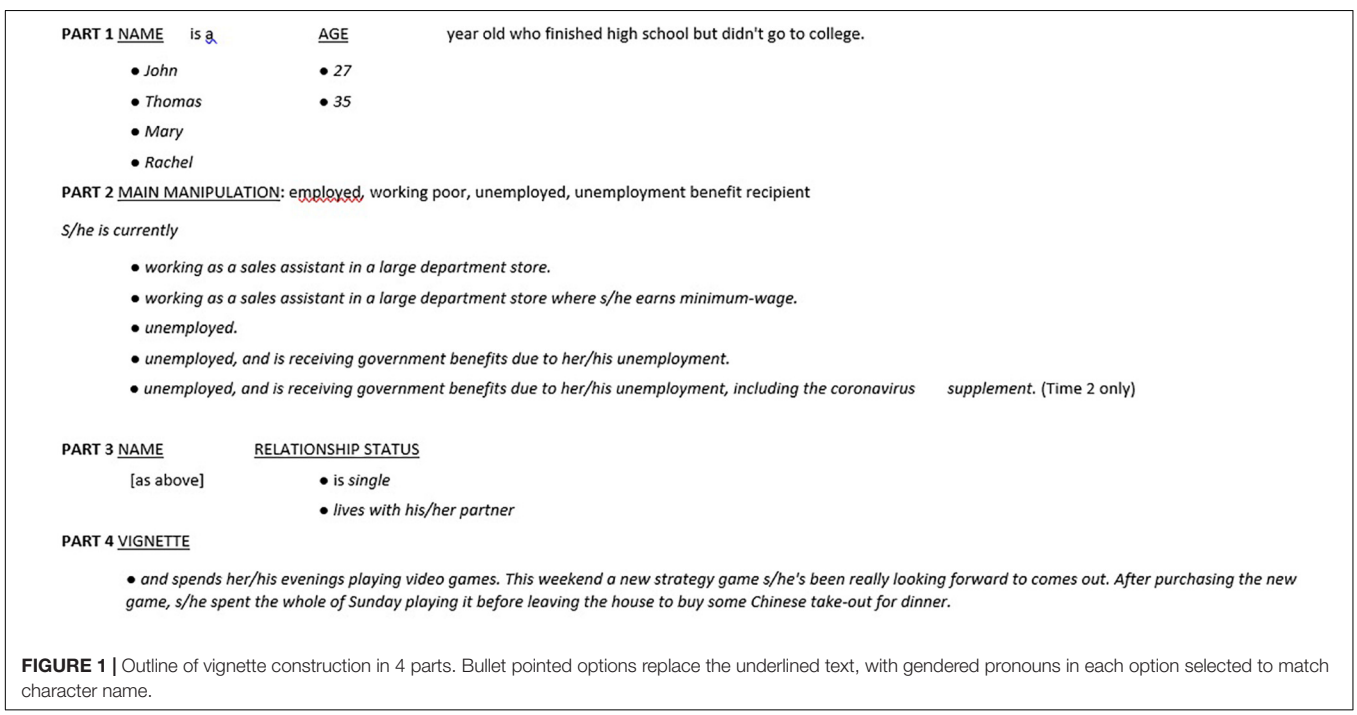

FIGURE 1 | Outline of vignette construction in 4 parts. Bullet pointed options replace the underlined text, with gendered pronouns in each option selected to match character name.

paired attributes. One item contained positive attributes and one contained negative attributes. Participants indicated the extent to which "I think [Name] is [attributes]" from 1 (strongly disagree) to 7 (strongly agree). The order of these 10 items was randomized. Agreeableness (α = 0.54) was assessed from "sympathetic, warm" and "critical, quarrelsome" (reversed); Extraversion (α = 0.50) was assessed from "extraverted, enthusiastic" and "reserved, quiet" (reversed); Conscientiousness (α = 0.76) was assessed from "dependable, self-disciplined" and "disorganized, careless" (reversed); Openness to experience (α = 0.36) was assessed from "open to new experiences, complex" and "conventional, uncreative" (reversed); Emotional stability (α = 0.65) was assessed from "calm, emotionally stable." and "anxious, easily upset" (reversed). The order of these 10 items was randomized.

Employability

Single item measures: "I think [Name] would be a good worker" (*Worker suitability*) and "I think [Name] would be a good boss" (*Boss suitability*) were rated on the same scale as the personality measure. The order of these two items was randomized. Higher scores indicated better employability.

Communion and Agency

Communion and agency was assessed using Bocian et al. (2018) adaptation of Abele et al. (2016) scale that measures the fundamental dimensions of communion and agency using two-subscales for each dimension. The morality and warmth subscales are seen as measures of communion (referred to as warmth in SCM; Fiske, 2018); while the competence and assertiveness subscales measure agency (what Fiske refers to as competence in SCM; Fiske, 2018). This subscale structure has been identified in multiple samples. Participants indicated the extent to which "I think [Name] [attributes]" from 1 (not at all) to 5 (very much so). Morality (α = 0.92) was measured with six items, e.g., "is just," "is fair"; Warmth (α = 0.96) with six items, e.g., "is caring," "is empathetic"; Competence (α = 0.90) with five items, e.g., "is efficient," "is capable"; and Assertiveness (α = 0.83) with six items, e.g., "is self-confident," "stands up well under pressure." These items were presented in a random order.

Dehumanization

Dehumanization was measured with a composite scale of two-items drawn from Bastian et al. (2013). Based on prior research, we measured dehumanization with two items: "I think [Name] is mechanical and cold, like a robot" and "I think [Name] lacked self-restraint, like an animal" order of these two items was randomized. We reverse coded the two items for the analyses for consistency for the other variables, so that higher scores were indicative of more favorable perceptions.

Moral Emotions

Moral emotions were measured by four items that asked about emotional responses to the character that were framed as self-condemning or other-condemning (Haidt, 2003; Giner-Sorolla and Espinosa, 2011). Two other-condemning items asked the participant about their own emotional response to the character in the vignette (Anger: "[Name]'s behavior makes me angry"; Disgust: "I think [Name] is someone who makes me feel disgusted," α = 0.92). The two self-condemning items asked about the character's emotional response (Guilt: "[Name] should feel guilty about [his/her] behavior"; Shame: "I think [Name] should feel ashamed of [him/her]self"; α = 0.95). We reverse coded the two scales to ensure consistency with other variables, with higher scores indicative of more favorable perceptions.

Analytical Strategy

With the exception of the Moral emotion (and Communion and Agency) scales that are new to this study and the previously tested Openness to Experience, our previous research has demonstrated differences between the ratings of employed and unemployed characters on the included outcome measures (Schofield and Butterworth, 2018b; Schofield et al., 2019). We undertake the analysis using a four-step process. We use mixed-effects multi-level models, with the 14 outcome measures nested within participants, and predicted by fixed (between-person) terms representing the experimental "Condition," "Time" (pre-/COVID19) and their interaction, and controlling for measure differences and allowing for random effects at the participant level: i) We initially assessed the effect of condition in the pre-COVID19 occasion to establish the baseline pattern of results; ii) we then evaluated the interaction term and, specifically, the extent to which the baseline difference observed between employment and unemployment conditions is attenuated at Time 2 (COVID19 occasion); iii) we tested the three-way interaction between condition, occasion and measure to assess whether this two-way interaction varies across the outcome measures; and if significant iv) repeated the modeling approach using separate linear regression models for each outcome measure. Our initial model contrasts the two employed (employed and working poor) and unemployed (unemployed and benefit receipt) conditions. The second model examines the four separate vignette conditions separately, differentiating between unemployed and unemployed benefit conditions. Finally, we contrast the three unemployment benefit conditions: (1) unemployment benefit recipients at Time 1; (2) unemployment benefit recipients at Time 2; and (3) unemployment benefit recipients receiving the Coronavirus payment at Time 2. For all models, we consider unadjusted and adjusted results (controlling for participant demographics). To address a potential bias from gender differences between samples, post-stratification weights were calculated for the COVID19 sample to reflecting the gender by age distribution of the pre-COVID19 sample. All models were weighted.

RESULTS

The two samples from Time 1 (pre-COVID19) and Time 2 (COVID19) were comparable on all demographic variables, except for gender (χ^2 [1, 923] = 7.04, $p < 0.001$) and employment (χ^2 [1, 910] = 27.66, $p < 0.001$): The gender distribution was more balanced at Time 1 with 49.8% of males, compared to 59.5% of males at Time 2. There was also a significant increase in unemployment with 20.9% of Time 1 participants out of work compared to 39.3% of the Time 2 participants. This was likely

reflective of the employment rate nearly doubling in Australia during COVID19 crisis. Bivariate correlations showed significant positive correlations between all 14 outcomes (p's < 0.001), except for Extraversion that was only positively correlated with Emotional Stability, boss suitability, warmth, assertiveness, and competence (p's < 0.05).

Contrasting Employed and Unemployed Characters

The results, both adjusted and unadjusted, from the initial overall multilevel model using a binary indicator of whether vignette characters were employed (those in the employed or working poor conditions) or unemployed (unemployed or welfare) and testing the interaction between vignette Condition and Time (pre-COVID19 vs COVID19) are presented in the **Supplementary Table S1**. The adjusted results (holding participant age, gender, employment, and education constant) indicated that the unemployed characters were rated lower than the employed characters at Time 1 ($b = -0.57$). This difference in the ratings of employed and unemployed characters was reduced in the COVID19 assessment at Time 2, declining from 0.57 to 0.26, across all the outcome measures. The addition of the three-way interaction between Condition, Time and outcome measure significantly improved overall model fit, χ^2 (52) = 482.94, $p < 0.001$, indicating the interaction between Condition and Time varied over measures.

A series of separate regression models considering each outcome separately (see **Supplementary Table S2**) showed a significant effect of Condition (employment rated higher than unemployment) at Time 1 (pre-COVID) for all outcomes except Openness and Extraversion. The lower ratings for unemployed relative to employed characters were significantly moderated at Time 2 on the Competence, Worker and Boss suitability, and Guilt/Shame outcomes (p's < 0.05).

COVID19 and Perceptions of Unemployment Benefit Recipients

The next set of analyses consider the four separate vignette conditions, differentiating between the unemployed and unemployed benefit recipient conditions. The overall mixed-effects multilevel model incorporating the four distinct vignette conditions provided evidence of significant effects for Condition and Condition by Time in both adjusted and unadjusted models. The result for the adjusted model (**Table 1**), averaged across the various outcomes, replicated the previous finding of a difference in ratings of employed and unemployed characters at Time 1 (pre-COVID19): relative to the employed condition, there was no difference in ratings of the working poor, but the unemployed and the unemployed benefit recipient characters were rated less favorably. There was some evidence of a gradient across the unemployed characters: the average rating of the unemployed condition was higher than the unemployed benefit condition, though this difference was not statistically significant. In the presence of the interaction effect, the non-significant effect of Time shows that, averaged across all the outcome measures, there was no difference in the rating of the characters in the employed condition on the pre-COVID19 and COVID19 occasions. We tested for the effect of sociodemographic characteristics as covariates in the adjusted models (employment and benefit receipt status, education, age, and gender) but found no main effects of any of the covariates except for gender: females tended to rate characters higher ($b = 0.13$, 95% CI [0.04, 0.21]) compared to males. Testing the heterogeneity of these patterns across outcomes via the inclusion of a three-way interaction between vignette condition, occasion and measure significantly improved overall model fit, χ^2 (104) = 533.40, $p < 0.001$, prompting analysis of each outcome separately.

TABLE 1 | Adjusted fixed effects estimates of outcomes as a function of interactions between condition and time.

	Coeff.	SE (robust)	z	p	[95% CI]	
Time (ref Time 1)						
Time 2	−0.06	0.09	−0.73	0.47	−0.24	0.10
Condition (ref E)						
WP	0.02	0.10	0.18	0.86	−0.19	0.22
UE	−0.50	0.11	−4.70	<0.001	−0.71	−0.29
UB	−0.61	0.11	−5.84	<0.001	−0.81	−0.41
Time × Condition						
Time 2 WP	0.01	0.12	0.11	0.91	−0.23	0.26
Time 2 UE	0.22	0.13	1.74	0.08	−0.03	0.47
Time 2 UB	0.33	0.13	2.51	0.01	0.07	0.58

Conditions: E, employed; WP, working poor; UE, unemployed; UB, unemployment benefits.

The separate linear regressions for each outcome measure (**Supplementary Table S3**) show that ratings of unemployed benefit recipients at the Time 1 (pre-COVID19) were significantly lower than the employed characters for all outcomes except Openness and Extraversion. Statistically significant Condition by Time terms indicated that the unemployed benefit effect was moderated at Time 2 (COVID19) for the three key outcome measures identified in previous research (Conscientiousness, Worker and Boss suitability) and for the measure of Guilt and Shame. **Figure 2** depicts this interaction for these four outcomes. These occurred in two profiles. For Conscientiousness, Worker and Boss suitability, COVID19 attenuated the negative perceptions of unemployed relative to employed characters, providing support for Hypothesis 2. By contrast, COVID19 has induced a new difference, such that participants thought employed characters should feel higher levels Guilt and Shame at Time 2, compared to Time 1. While the "working poor" condition was not central to the COVID19 hypotheses, we note that we found no evidence that ratings of these characters on any outcome differed from the standard employed character, or that this difference was changed in assessment at Time 2 (COVID19 occasion).

The Impact of COVID19 on Perceptions of Unemployment Benefit-Recipients

The inclusion of the fifth COVID19-specific unemployment benefit condition did not generate more positive (or different) ratings than the standard unemployment benefit condition.

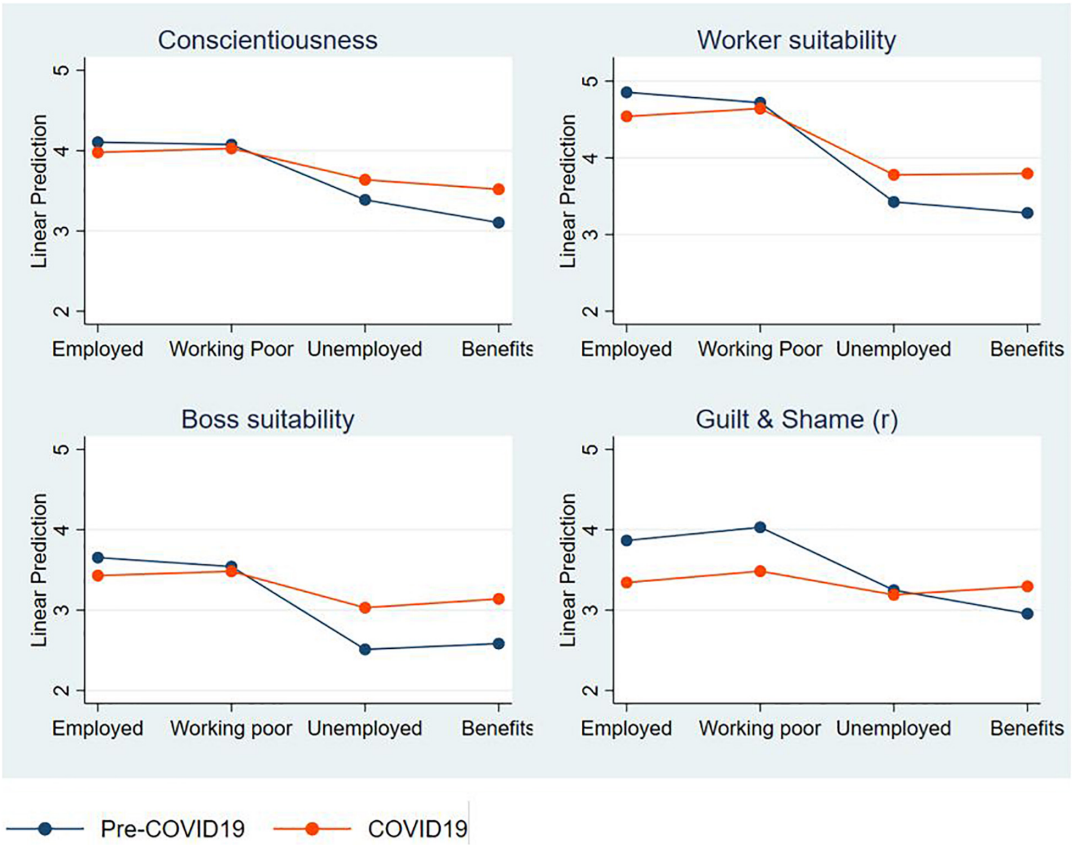

FIGURE 2 | Interaction effect of Time (COVID19) by Condition marginal mean ratings on four outcomes: Conscientiousness, Worker suitability, Boss suitability, and Guilt and Shame (reversed).

Overall mixed-effects multilevel models, both adjusted and unadjusted, indicated that participants in the Coronavirus supplement condition (adjusted model: b = 0.26, 95% CI [0.06, 0.45]) and the general unemployed benefit recipient condition at Time 2 (adjusted model: b = 0.28, 95% CI [0.08, 0.48]) were both rated more favorably in comparison to unemployed benefit recipients at Time 1. There was no difference between these two Time 2 benefit recipient groups (b = 0.03, 95% CI [−0.12, 0.19]). These results did not support hypothesis 3.

DISCUSSION

Previous research has demonstrated that people who are unemployed, and particularly those receiving unemployment benefits, are perceived more negatively and less employable than those who are employed. However, the economic shock associated with the COVID19 crisis is likely to have challenged people's sense of their own vulnerability and risk of unemployment, and altered their perceptions of those who are unemployed and receiving government support. The broad aim of the current study was to examine the potential effect of this crisis on person perceptions tied to employment and benefit recipient status. We did this by presenting brief vignettes describing fictional characters, manipulating key experimental conditions related to employment status, and asking study participants to rate the characters' personality and capability. We contrasted results from two cross-sectional general population samples collected before and during the COVID19 crisis.

The pre-COVID19 assessment replicated our previous findings (e.g., Schofield and Butterworth, 2018b) showing that employed characters are perceived more favorably than those who were unemployed and receiving government benefits on measures of Conscientiousness and suitability as a worker. These findings supported Hypothesis 1. In comparison, the assessment conducted during the COVID19 crisis showed that unemployed and employed characters were viewed more similarly on these same key measures, with a significant interaction effect providing support for Hypothesis 2. Our third hypothesis, suggesting that n reference to the Coronavirus Supplement (an additional form of income support introduced during the pandemic) would enhance ratings of unemployed benefit recipients at the second assessment occasion, was not supported. We found that benefit recipients at Time 2 were rated more favorably than the benefit group at Time 1, irrespective of whether this COVID19-specific payment was referenced. This suggests the broader context in which the study was conducted was responsible for the change in perceptions.

We sampled participants from the same population, used identical experimental procedures, and found no difference over time in the ratings of employed characters on the key outcome measures of employability (Worker and Boss suitability) and Conscientiousness. The more favorable ratings of unemployed and benefit receiving characters at Time 2 is likely to reflect how the exogenous economic shock brought about by the COVID19 crisis challenged social identities and the stereotypes held of others[4]. The widespread impact and uncontrollable nature of this event are inconsistent with pre-COVID19 views that attribute ill-intent to those receiving to unemployment benefits (Fiske et al., 2002; Baumberg, 2012; Contini and Richiardi, 2012; Bye et al., 2014). We suggest the changing context altered perceptions of the "deservingness" of people who are unemployed as unemployment in the context of COVID19 is less indicative personal failings or a result of one's "own doing" (Petersen et al., 2011; van Oorschot and Roosma, 2017). It is important to recognize, however, that the negative perceptions of unemployed benefit recipients were attenuated in the COVID19 assessment, but they continued to be rated less favorably than those who were employed on the key outcome measures.

In contrast to our findings on the key measures of employability and Conscientiousness, the previous and current research is less conclusive for the other outcome measures. The current study showed a broadly consistent gradient in the perception of employed and unemployed characters for all outcome measures apart from Openness and Extraversion. Findings on these other measures have been weaker and inconsistent across previous studies (Schofield and Butterworth, 2018b; Schofield et al., 2019), and the current experiment was not designed with sufficient power to demonstrate interaction effects for these measures. There was, however, one measure that showed significant divergence from the expected profile of results. A significant interaction term suggested that study participants at the Time 2 (COVID19) assessment reported that the employed characters should feel greater levels of Guilt and Shame than those who participated in the pre-COVID19 assessment. In contrast, there was consistency in the ratings of unemployed characters on this measure across the two assessment occasions. While not predicted, these results are also interpretable in the context of the pervasive job loss that accompanied the COVID19 crisis. Haller et al. (2020), for example, argue that the highly distressing, morally difficult, and cumulative nature of COVID19 related stressors presents a perfect storm to result in a guilt and shame responses. The context of mass job losses may leave "surviving" workers feeling increasingly guilty.

The main findings of the current study are consistent with previous experimental studies that show that the stereotypes of unemployed benefit recipients are malleable (Aarøe, 2011; Schofield et al., 2019). These previous studies, however, have demonstrated malleability by providing additional information about unemployed individuals that was inconsistent with the unemployed benefit recipient stereotype (e.g., the external causes of their unemployment). In contrast, the current study did not change how the vignette characters were presented or the experimental procedures. Rather, we assessed how the changing context in which study participants were living had altered their perceptions: suggesting the experience of COVID19 altered stereotypical views held by study participants rather than presenting information about the character that would challenge the applicability of the benefit recipient stereotype in this instance.

Perceptions and stereotypes of benefit recipients can be reinforced (and potentially generated) by government actions and policies. Structural stigma can be used as a policy tool to stigmatize benefit receipt as a strategy to reduce dependence on income support and encourage workforce participation (Moffitt, 1983; Stuber and Schlesinger, 2006; Baumberg, 2012; Contini and Richiardi, 2012; Garthwaite, 2013). In the current instance, however, the Australian government acted quickly to provide greater support to Australians who lost their jobs (e.g., doubling the rate of payment, removing mandatory reporting to the welfare services) and this may have reduced the stigmatizing structural features of the income support system and contributed to the changed perceptions of benefit recipients identified in this study.

Limitations

The current study took advantage of a natural experimental design and replicated a pre-COVID19 study during the COVID19 crisis. The study is limited by the relatively small sample size at Time 1, which was not designed for current purposes but part of another study. We were not able to include most of the participants from the original Time 1 study as most of the experimental conditions described activities that were illegal/inconsistent with recommend activity at the time of the COVID19 lockdown and social restriction measures. Finally, the data collection for the current study occurred very quickly after the initial and sudden COVID19 lockdowns and economic shock, which is both a strength and a limitation for the generalizability of the results. The pattern of results using the same sampling frame offers compelling support for our hypothesis that the shared economic shock and increase in unemployment attenuates stigmatizing community attitudes toward those who need to receive benefits. Our current conclusions would be further strengthened by a subsequent replication when the public health and economic crises stabilize, to test whether pre-COVID perceptions return.

CONCLUSION

The current study provides novel information about impact of the COVID19 health and economic crisis, and the impact of the corresponding policy responses on community perceptions. This novel study shows how community perceptions of employment and benefit recipient status have been altered by the COVID19 pandemic. These results add to knowledge about the determinants of welfare stigma, particularly relating to employability, highlighting societal level contextual factors.

[4]https://pursuit.unimelb.edu.au/articles/our-changing-identities-under-covid-19

DATA AVAILABILITY STATEMENT

The raw data supporting the conclusions of this article will be made available by the authors, without undue reservation.

ETHICS STATEMENT

The studies involving human participants were reviewed and approved by Melbourne University Human Research Ethics Committee. The patients/participants provided their written informed consent to participate in this study.

AUTHOR CONTRIBUTIONS

AS led the review conceptualized by TS and PB. AS and PB conducted the analyses and wrote up the review. TS led the data collection, reviewed and edited the manuscript, and provided data management support. This manuscript is based on previous extensive work by TS and PB on stereotypes toward the unemployed and welfare benefit recipients. All authors contributed to the article and approved the submitted version.

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SUPPLEMENTARY MATERIAL

The Supplementary Material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/fpsyg.2020.594837/full#supplementary-material

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Conflict of Interest: The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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COVID-19 Pandemic: Socio-Economic Consequences of Social Distancing Measures in Italy

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The lock-down measures adopted in all countries of the world have led to far-reaching social and economic changes. The health emergency had immediate repercussions first on the social system and then on the economic one. The social repression measures taken to limit the infection have generated a drastic change in daily life, detaching ourselves from the other emotionally and physically. The already difficult situation that Italy was experiencing from an economic and social point of view is immediately exposed by the health emergency, and then worsened and extended to all sectors. In this context, it is important to study different types of phenomena: the suspension of commercial activities and the consequent repercussions on the work sector, smart-working and infrastructural and cultural digital divide, the new forms of interaction and relationship that transform the emotions and, finally, the enormous fluctuation of world markets. To face such a far-reaching crisis, the measures taken not only at national level, but also supranational and international will be decisive.

Keywords: coronavirus, digital divide, economy, empathy, social distance, work

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INTRODUCTION

On January 30, 2020, China reported to the world the existence in the city of Wuhan of a cluster of cases of pneumonia of unknown etiology (later identified as a new coronavirus Sars-CoV-2), the same day the WHO (World Health Organization) declared the international state of emergency. The following day, January 31, the Italian government proclaimed a state of emergency and implemented the first measures to contain the infection throughout the national territory. One of the first measures adopted was the suspension of all flights to and from China with the implementation of airport controls, using thermoscanners for measuring body temperature, in order to monitor the health conditions of passengers from China through stopovers intermediate. The increase in health checks was immediately foreseen also in ports, involving not only non-EU boats but all merchant and cruise boats in transit on the national territory. On February 21, the Ministry of Health introduced mandatory quarantine isolation measures for close contacts with a case that tested positive for Covid-19, and ordered active surveillance with fiduciary home stay for those who were in risk areas in the last 14 days, with the obligation of reporting by the interested party to the local health authorities. On 23 February, following the outbreaks registered in Lombardy and Veneto, the first "red zone" was established, some municipalities were isolated (ban on expulsion and ban on access) and were suspended in them all educational and cultural activities, economic, commercial and recreational-recreational activities guaranteeing citizenship access to essential services and goods. On February 25, some measures to contain the contagion, concerning the suspension of sporting events, school activities and higher education

(recommending the implementation of distance learning), cultural and tourism activities and driving exams, were extended to all the municipalities of the Regions: Emilia-Romagna, Friuli Venezia Giulia, Lombardy, Veneto, Liguria and Piedmont. On 1 March the same Regions entered the "red zone." On 4 March, educational activities in schools and universities, congress activities, cultural events and sporting events were suspended throughout the country, recommending the use of agile work. On 8 March, a single containment area was created with more stringent measures including the territory of the Lombardy Region and 14 other Provinces (five from Emilia-Romagna, five from Piedmont, three from Veneto and one from Marche). With the DCPM (Presidential Decree of the Council of Ministers) 8 March, respect for the interpersonal safety distance of at least one meter is introduced for the first time as a containment measure and the need to avoid gatherings is highlighted several times, the use of the mask is instead recommended only to those who suspect to be sick and to those who care for sick people[1]. On 9 March the "red zone" is extended to the whole national territory and will remain in force until 4 May.

Maintaining social distance seems to be the most effective health device for preventing Covid-19 contagion. Since the coronavirus began its diffusion, two types of distances were recognized: one refers to the distance between individuals (gatherings) and the other to the distance that each individual must keep on the other, in order to avoid contagion (Bignami, 2020; CDC, 2020; Demarais, 2020). Social distance, sociology and social psychology, mean the willingness of members of one group to have social contacts with people from another group. In particular, it is studied in which way people are ready to exclude or admit those who belong to another group (Canavese, 2020). It is important to know that this measure is not new, its first application, even if not in these terms (1.8 million), dates back to September 1918, toward the end of the First World War, when a bad influence began to spread throughout the world. The virus responsible for the disease, which became known as Spanish flu, infected over a quarter of the world's population, with an estimated death toll of 50 to 100 million, it became one of the deadliest pandemics in human history. The first prohibitions and the first "social distances," although they did not use this term correctly, began in the United States. At that time, some cities were organizing parades to promote ties of freedom, with the aim of helping to pay for the war efforts in Europe. In Philadelphia, Pennsylvania, where 600 soldiers had already been infected with the flu virus, a never-adopted rule was introduced, quarantine and social distance within the family system (Pottinger, 2013; Bourouiba, 2020; Carlini, 2020; Resnick, 2020).

The objective of this work is to investigate the consequences produced by the measures adopted by the Italian government, and subsequently by many other European and non-European countries, to deal with the Covid-19 pandemic starting from an analysis of the situation prior to the crisis and investigating some of the possible future scenarios. As is well-known, Italy suffers from various structural deficiencies made even more acute in the last decade by the economic policy recipes adopted for the restructuring of the exponential national public debt. The Covid-19 emergency had the merit, or demerit, of unmasking the deficits that have existed in Italy for years in all sectors of activity, public and private, and urgently imposes the need to remedy dramatically chronic situations, the result of political and economic actions. The importance of well-being, the importance of income and the critical issues raised by ever more marked inequalities have been rediscovered.

[1]The obligation to wear a mask has not been introduced uniformly on the national territory. This obligation was mostly provided for in a "transversal" way, that is only for certain population groups (health professionals, commercial operators of basic necessities such as food, pharmacies, etc.) and, in any case, only at the regional level.

THE CONSEQUENCES OF SOCIAL DISTANCES

Economy and Work

The Istat (National Institute of Statistics) note on employed and unemployed of February 2020 shows a stable employment rate at 58.9%, the result of a slight increase in employment among women (+12 thousand units), temporary employees (+14 thousand) and young people aged 15 age 24 (+35 thousand) and a drop in employment among men (−22 thousand units), permanent employees (−20 thousand), self-employed persons (−4 thousand), and over 35 (−44 thousand) (Istituto Nazionale di Statistica, 2020b). The inactivity rate stands at 34.5% with an increase in February of women and people aged at least 35 equal to 12 thousand units. In the same month, women seeking employment (−39 thousand units) and the over 35s decreased, while men (+22 thousand units) and young people between 15 and 24 years increased. Unemployment stood at 9.7%, with a slight decrease of 0.1%, while youth unemployment remained stable at 29.6%. Comparing the December 2019–February 2020 quarter with the previous one, September–November 2019, there is a clear decline in employment (−89 thousand units) involving both gender components between 15 and 49 years, permanent employees and self-employed while it sees a slight growth among temporary employees. In the same quarter, the number of people seeking employment decreased and the inactive increased (+51 thousand units) (Istituto Nazionale di Statistica, 2020b). A not at all rosy pre-crisis picture that substantially records an increase in precarious work, a strong mistrust in the future and a dramatic youth condition. An even less comforting situation if you look at the latest data made available by the 2019 statistical yearbook on poverty (Istituto Nazionale di Statistica, 2019a,b,c). In 2018 the percentage of families in absolute poverty in Italy was 7% (882 thousand) with an alarming incidence in the South where the value stood at 20.5% (higher than the national average of 19.4%) (Istituto Nazionale di Statistica, 2019a,b,c). The highest incidence is recorded among families with five and more components (19.6%), followed by couples with three or more children (16.6%), single-parent families (11.4%) and families with four components (8.9%). The lowest incidence is recorded among families of and with the elderly (4%) and further decreases in families in which the reference person is over 64 years old (3.2%). On an individual level 8.4% of the entire population is in conditions of

absolute poverty, of the 5 million and 40 thousand individuals in this condition over 2 million and 300 thousand reside in the South (11.4%) and over 2 million and 500 thousand are women (8.3%). The incidence of absolute poverty is high among minors (12.6%) and people aged between 18 and 34 (10.3%), confirming its minimum among over 74 years (4.6%) (Ibid). The elderly population in Italy proves to be the main social safety net, a figure that should not be underestimated if we consider that most of the deaths from Covid-19 belong to the age group between 60 and 90 years of age and over, on April 13, 2020 the number of deaths between 60 and 69 years is 11.5% of the total, between 70 and 79 years at 31.5%, between 80 and 89 years at 40.4% and among people over 90 years of age 11.6% (Il Sole 24 Ore., 2020).

Decisions on adopting social distance have inevitably involved almost all productive activities. In Italy, according to the ISTAT note on the economic trend of the month of March, the activities of 2.2 million companies, 49% of the total, have been suspended, investing the exporting companies to a greater extent, involving 65% of the total. The blockade of production activities involved 44.3% of employees and 42.1% of employees. The first response recorded by the National Statistical Institute is a sharp collapse in consumer and business confidence (Istituto Nazionale di Statistica, 2020a). In addition to the direct effects connected with the suspension of the work activities, the production sector also suffers from the indirect effect related to the cross-sectoral relations. An example is given by the expenses for fuels and land transport (for example bus) services which have fallen sharply and the expenses for tourism which have been completely eliminated. The first estimate of the effects of the blockade on ISTAT'S economic performance is not reassuring. In this situation, two types of scenarios have been hypothesized. The first one is related to the possibility that the limitation of production activities is limited only for the months of March and April, a reduction in final consumption of 4.1% is estimated, with a decrease in value added generated by the production system of 1.9%, involving 385 thousand employees, of which 49 thousand irregular, for an amount of approximately 9 billion euros in salaries. The most expensive price of the drop in value added is paid by the accommodation and restaurant services (−11.3%) and by the commerce, transport and logistics sectors (−2.7%), while the consequences on the less incisive sectors they are: producing investment goods and construction (less than one percentage point) (Istituto Nazionale di Statistica, 2020a).

The second one concerns the extension of the measures to the months of May and June, leading the reduction in consumption of 9.9%, with an overall reduction in added value of 4.5%, involving 900 thousand employees, of whom 103 thousand non-regular, for a total of 20.8 billion euros in salaries. Also, in this case the most marked contractions of the added value would involve the restaurant and restaurant business (−23.9%), trade, transport and logistics (−6.9%) with more marked effects on the production of consumer goods (−3.6%), personal services (−3.6%) and professional services (-3.4%). In this scenario, commercial services and "socialization" would pay the most expensive price, with a drop in value added of −16.4% in the cultural sector, −12.7% in the entertainment sector and −6.7% in the retail trade, potentially affecting 608 thousand employees, of whom 72 thousand are not regular (Istituto Nazionale di Statistica, 2020a).

In March, there was a slowdown in inflation attributable, according to ISTAT, to the slowdown in unregulated energy goods (−2.7%) and services (from + 1% to + 0.6%), these trends of decreases were only partially offset by the acceleration in food prices (from + 0.4% to + 1.2%) and tobaccos (from + 1.5% to + 2.5%) (Istituto Nazionale di Statistica, 2020a).

To date it is still difficult to estimate the number of people who, due to the Covid-19 emergency, could find themselves out of a job as it is difficult to predict the number of small and medium-sized enterprises that will be able to resist and get to phase 2, considering that many of them are already suffering. For now, a number of workers at risk of 10 million is assumed, based on this estimate the State has made 10 billion available with a bonus of 600 euros for 5.3 million workers who will reach 800 in April and May, while for the precarious, who demonstrate that they have worked at least 4 weeks a year, 400–500 euros per month were paid (Livelli, 2020; Mondani, 2020). An insufficient measure if we consider all those precarious workers of the informal economy which in the South amount to about 50%. Law Decree April 8, 2020, n. 23 (Urgent measures regarding access to credit and tax obligations for businesses, special powers in strategic sectors, as well as interventions in the field of health and work, extension of administrative and procedural conditions) "Credito" has disbursed € 400 billion in addition to the 350 billion already allocated by the decree 18/2020 "Cura Italia", 200 billion were allocated to give liquidity to companies for those involved in the internal market and for those dedicated to exports. Again, the measures may be insufficient, in addition to the loans, non-repayable loans have not been disbursed (Istituto Nazionale di Statistica, 2020a).

The economic and financial crisis generated by this health emergency could have even more damaging consequences than the recent 2008 subprime mortgage crisis, because every new coronavirus outbreak in the world breaks the chains of a production system that is now strictly close interconnected globally. This is a shock that affects both demand and supply simultaneously and could cause generalized declines in production and supplies together with a recovery in inflation (Istituto Nazionale di Statistica, 2020a). Humanity is facing an unprecedented global crisis which, unlike the barriers raised by nationalist policies, has no borders. According to the International Monetary Fund (2020), 3% of world GDP (Gross Domestic Product) will increase in 2020, with economic losses of about 9,000 billion dollars, indiscriminately affecting rich and poor countries. Global supply chains have major flaws and the financial crisis involves markets and raw materials; advanced economies will pay the most expensive price with a contraction of −6% of GDP while for emerging countries it will be equal to 1%. The Eurozone will lose 7.5% of GDP, the taillight, immediately after Greece, Italy is for which a contraction of −9.1% is expected (Istituto per gli Studi di Politica Internazionale, 2020). In presenting the reports on the world economy in April 2020, the director of International Monetary Fund, Kristalina Georgieva, said that the ongoing crisis will

lead to the worst economic fallout of the Great Depression, if an increase in per capita income was expected 3 months ago in over 160 member countries of the negative growth of the IMF is now forecast for 170 countries (Istituto Nazionale di Statistica, 2020a). Angel Gurria, OECD secretary general, said that in the event that countries manage to respond promptly to the shock and with appropriate measures, the recovery curve will resemble a U, with a long period of suffering that will last for years, otherwise it could become an L (Szu, 2020). This crisis presents several peculiarities, first of all the uncertainty of its duration and intensity, which is still impossible to define today, and also the impossibility of giving impetus to the economy with the usual measures, how to stimulate aggregate demand, where these they are undesirable for those sectors, most affected in compliance with containment measures (International Monetary Fund, 2020). As stated by Gita Gopinath, IMF economic consultant, this crisis must be faced in two phases: one of containment and stabilization and the other of recovery. In the first phase, blocking and social distancing measures are essential to slow down the transmission of the virus and give the health system time to expand its services and try to develop a vaccine through the right flow of resources. At the same time, it is essential that states implement the fiscal, monetary and financial measures necessary to keep the company's economic infrastructure intact. To reduce systemic stress, liquidity must be introduced to counteract loss of confidence and strengthen expectations for economic recovery. Governments and central banks will have to take a leading role in economies with the support of international financial institutions and bilateral economic creditors. Economic policy actions will determine the conditions for recovery, the protection of people and businesses will be essential (International Monetary Fund, 2020).

Smart-Working and Connectivity

The total blockade at different levels- educational institutions, commercial activities, industrial production-has placed Italy facing an unprecedented challenge. In a country that has been trying to adapt to the digitalization process have emerged strongly problems related to unequal technological development, which travels at different speeds along the national territory. The problems opened up by the need to activate intelligent working methods, in all those sectors in which there is no urgent need for physical presence and/or manual work, are manifold and embrace different aspects ranging from structural issues to personal problems and needs. The digital divide essentially refers to two forms of inequality that have manifested themselves in access to adequate Internet coverage (digital infrastructure gap) and in the use of information technology (digital cultural divide).

Digital Infrastructure Divide

The European Commission defines the digital infrastructure divide as the lack of fixed broadband coverage of at least 2 megabits. According to the latest DESI report of 2019 (The Digital Economy and Society Index), 99.5% of Italian families are served by fixed broadband, fast broadband (NGA - Next Generation Access) reaches 90% of families while only 24% it is obtained from ultrafast broadband (100 Mbps and above) (The Digital Economy Society Index, 2019). Data from the Ministry of Economic Development, referring to the last national public consultation dating back to 2017, show an even wider gap, stating that only 2% of national house numbers are reached by a connection >100 Mbps, 30% they have a connectivity higher than 30 Mbps, while almost 70% of citizens are not covered by the "ultra-wide" band (Calenda and Bentivogli, 2018). The variability of the data is dictated by the different calculation systems used but, whatever the results are closest to the real, it should be remembered that the actual navigation speed is lower than the maximum declared speed and on which these estimates are made. An emblematic example are the values of a speed test carried out by the team of University of Salerno on 17 January 2020, before therefore the coronavirus emergency, in a municipality in the province of Avellino located 725 meters above sea level, the Ospedaletto d'Alpinolo. Against a connection speed declared by the telephone operator at 20 Mbps, the actual download speed was 2.61 Mbps while the upload speed was 0.48 Mbps.

The latest Istat Citizens, Businesses and ICT (Information and Communication Technologies) report (2018) highlights a much more worrying situation. Italian families with internet access from home are 75.1%, of which 73.7% have broadband connection. In Europe, the average rate of broadband diffusion among resident households with at least one member aged 16–74 is 86%; Italy, with a rate of 83%, has a gap of 3 percentage points. Despite the growth in the number of households that have a broadband connection, the gaps still remain wide, 24.7% of households do not have access to the internet. More than one in two families declare that they do not have access to the internet at home because they do not know how to use it (58.2%), and more than one fifth (21.0%) do not consider the Internet a useful and interesting tool. There are economic reasons related to the high cost of connections or necessary tools (15.2%), while 8.1% do not surf the Net from home because at least one member of the family accesses the Internet from another place. On the other hand, the share of families who indicate insecurity with regard to the protection of their privacy (2.9%) and the lack of availability of a broadband connection (2.0%) among the reasons is residual (Istituto Nazionale di Statistica, 2019b). The main territorial gaps are found on the already known lines of inequality: north-south, city-countryside, scattered houses of urban agglomerations, coastal areas-inland areas, hilly areas-mountainous areas, continental islands.

The containment measures adopted to deal with the Covid-19 emergency have had a strong impact on the already inadequate situation of country's infrastructural network, causing an overload and a further slowdown of the same. The transition to digital does not only concern work needs but all areas of daily life, from relationships to video lessons, from recreational activities to purchases. Joy Marino director of Milano Internet Exchange, the main hub of Italian connections to and from abroad, said that in the week between 9 and 15 March there was an increase of 112% in terms of use of virtual private networks (VPN) (Levels, 2020). As is known, the problem is not limited to Italy, as of April 9, 2020 according to WHO

data, 216 countries are affected by the epidemic with a total of 1,439,013 confirmed cases and 85,587 deaths (WHO, 2020), while according to when reported by AFP, the French news agency, about 4 million people are currently confined to their homes (AFP, 2020).

From late February to late March, global Internet traffic increased by 30% with an increase in bytes consumed of about 10 times compared to the average monthly data (Ruscono, 2020). In the countries affected first by Covid-19 (China, Korea, Japan, and Italy) there have been variations in Internet traffic 25% higher than the rest of the world in the same period of time, in Italy the growth in connections has been constant since beginning at the end of March (Ruscono, 2020). The Facebook CEO said that in all the countries affected by Covid-19 a very high use was made not only of WhatsApp but also of Facebook and Messenger (Levels, 2020). In Italy, the time spent on WhatsApp, Messenger and Instagram has increased by 70% since the start of the pandemic, the duration of calls on Messenger and WhatsApp has increased by more than 1,000% while the exchange of messages on these apps has increased by 50%. The evening bands are those that register the maximum increase in connection to the network up to 100% (Levels, 2020). The main risks for intelligent work are related to the overload of the so-called public cloud services, located mainly outside Italy and Europe, which could be slowed down and interrupted by limiting or completely preventing access to the sharing and communication portals, by videoconference (Levels, 2020). The main concern is related to the increase of people simultaneously in isolation and the consequent exponential growth in the use of the various platforms dedicated to relationships, leisure activities and work needs, a scenario that could lead to an inclination of the server. The minister for technological innovation, Paola Pisano, promptly reassured the country by declaring that the network will be able to resist this data overload, but has also invited to use the Internet sparingly, calling it a "precious resource" (Sky Tg24, 2020). The Italian state immediately took steps to introduce the necessary means to avoid a possible collapse of the network, art. 82 of the legislative decree 17 March 2020, n. 18 (Measures to strengthen the national health service and economic support for families, workers and businesses related to the epidemiological emergency from Covid-19)— "Cura Italia" reads "Measures intended for operators who provide communication networks and services electronics" in which operators are asked to strengthen infrastructures to guarantee the functioning of the network and the continuity of services, favoring the functioning of the health and emergency sector (Levels, 2020). The European Commission asked the main video streaming platforms to reduce the quality and speed of video playback, measures readily adopted by Netflix, Youtube and Amazon, while asking users to privilege the fixed network over the mobile network for file playback multimedia. The International Telecommunication Union (ITU) has instead implemented a "Global Network Resilience Platform" with the aim of protecting the networks of various operators during the Covid-19 crisis and supporting governments in ensuring "safer" networks and with better performance (Levels, 2020). The need to accelerate the digitization process as much as possible and to pay the utmost attention to risk management and operational continuity of the network, which is the main ally in the attempt not to restore the country's productivity and to offer a semblance of normality to everyday life or maybe build a completely different one.

Digital Cultural Divide

The digital cultural divide highlights the division between the part of the population with digital skills from others who does not possess these skills. Digital exclusion seems to follow the already known lines of social discrimination, which affect the elderly, unemployed or women in particular conditions, immigrants, people with disabilities, prisoners and all those with low levels of education and training. The 2019 DESI report highlights the sharp gap between Italy and the rest of the European Union countries in terms of human capital. Italy ranks 26th with an average of 32.6% compared to the EU average of 48%, only 44% of people between 16 and 74 have basic digital skills while the percentage is even lower than people who possess digital skills higher than the basic ones equal to 19% (The Digital Economy Society Index, 2019). Even more worrying is the figure of the habitual use of the Internet by young people between 16 and 24 years of age, which sees Italy in last place among the 28 EU member countries with a percentage of 92% compared to 97 Average% of the EU (The Digital Economy Society Index, 2019). From 9 March the activities of educational institutions were suspended until a later date, the executive immediately recommended the implementation of distance learning to make it mandatory, with the law decree of 8 April 2020, n. 22 (Urgent measures on the regular conclusion and the orderly start of the school year and on the conduct of state exams) approved by the Council of Ministers, Monday 6 April.

The country has responded with different times and ways starting from irregular starting resources. As highlighted by the DESI 2019 report, the National Plan for digital school, launched in Italy in 2015, does not seem to have produced important results, only 20% of teachers have attended digital literacy courses and 24% of schools do not yet have courses of programming (The Digital Economy Society Index, 2019). On the same day that the government approved compulsory distance learning, ISTAT released a note entitled "Home spaces and availability of computers for children and adolescents" which highlights the difficulty situation in a country where inequalities continue to be high, especially along the north-south axis. Based on the data collected in the years 2018–2019, it appears that 33.8% of families do not have a computer or tablet at home, a percentage that drops to 14.3% among families with at least one minor and still decreases reaching 7.7% in families where at least one component has a degree, clarifying how the level of education weighs on the digital cultural divide (Istituto Nazionale di Statistica, 2020a,b,c). In the south the percentage of families without computers exceeds 41% compared to 30% in other areas of the country, the same gap occurs for the number of computers in homes in relation to the number of family members, in the south 26, 6% of Households has a number of PCs and tablets available for less than half of the components and only 14.1% have at least one for each component (Istituto Nazionale di Statistica, 2020a,b,c). Fifty

seven percentage of young people aged between 6 and 17 must share a computer or tablet with the family, this implies that even in cases where Internet access is present (96% of families) this does not guarantee the possibility to carry out distance learning also considering that this is generally the students at the same time as adults are engaged in intelligent work (Istituto Nazionale di Statistica, 2020a,b,c). In addition, a good level of connection is required to follow the online lessons, which prevents audio from skipping or blocking the video, Infodata has reworked ISTAT data (Aspects of daily life 2019) showing that families with a band connection wide fixed are two out of three in Lazio (figure > 62.2%) while they do not exceed 41% in Calabria and Basilicata with a greater penalty for residents of small municipalities (Orlando, 2020; Saporiti, 2020). As for digital skills, according to ISTAT data, only 30.2% of young people between 14 and 17 years of age have high digital skills, 3% do not have digital skills while about two thirds have low or base (Istituto Nazionale di Statistica, 2020a,b,c). The quality of work and home study are also strongly influenced by another important factor, housing conditions. According to ISTAT data from 2018, 27.8% of people in Italy live in conditions of housing overcrowding, a difficult condition experienced in particular by minors with a percentage of 41.9% living in conditions of overcrowding. A discomfort that is aggravated in the presence of structural housing problems such as cramped, poorly ventilated and poorly lit spaces, what Istat defines as serious housing deprivation concerns 5% of Italians, also in this case young people, 7.0% of minors and 7.9% of young people aged between 18 and 24 live in conditions of housing discomfort (Istituto Nazionale di Statistica, 2020a,b,c).

Social Distancing and Empathy

The response to the Covid-19 pandemic is infiltrating every aspect of life, social distance has generated serious consequences that are already being felt. The struggle against this invisible enemy could last for months or even years. Public health experts believe that social distancing is the best way to prevent a truly horrible crisis, beyond a certain threshold the national health system is unable to accept and treat people who require fans and intensive care units. To date, the only measure that seems to be working is the strict Social Distance policy. The elimination of these measures could now trigger new outbreaks that would seriously jeopardize public health. It is not possible to predict when the virus disappears and restrictive measures will continue for as long as necessary, seriously affecting social relationships and interactions, especially the empathic process. Empathy refers to the ability to put oneself in another person's situation or, more precisely, to understand the other person's emotional processes and respond in a congruent way. This term means a German term in Italian, Einfühlung (Treccani, 2019b). This term is placed at the base of the aesthetic theory elaborated by Vischer (1847–1933) and Lipps, according to whom art is the identification of feeling in natural forms, thanks to a deep consonance or sympathy between subject and object (Vischer and Vischer, 1887; Lipps, 1903). The individual attributes beauty to the forms in which he manages to transfer or project his vital sense. Aesthetic enjoyment is therefore objectified enjoyment of ourselves (Treccani, 2019a,b,c). Starting from the early 90s the problem of understanding empathy, understood as that form of identification in the psychological states, which more and more often fall into physiological states, of the other to which the explanation, or understanding, of his behavior would be subordinated at the center of a meaningful and lively debate in the philosophy of psychology and in the philosophy of the mind, which today falls within the cognitive sciences (Franks, 2010). Without prejudice to the reference to the historical models of empathic understanding by Dilthey (1833–1911), such as Verstehen by Weber (1864–1920), Schutz (1899–1959), Simmel (1858–1918) and the re-enactment of Collingwood (1889–1943), the renewed debate began with some developments in the analytical philosophy of language and mind, in particular with a thesis by Quine (1908–2000).

According to Quine, the attribution of the so-called propositional attitudes or intentional states, through which the psychology of common sense normally explains the behavior of individuals according according to the classic model of purpose of the means, is essentially based on an empathic simulation (Treccani, 2019a,b,c). This empathic simulation constitutes, for Quine, a natural epistemic modality with which beliefs, desires and perceptions are currently, and often unconsciously, attributed (Quine, 1990, 1992). Trying to analyze this aspect within the dynamics of life, it can be said that a "lowering of empathy levels" is very likely to occur. Although, on the one hand, there may be known cases, reported every day by newspapers and television news, in which one or more people identify with those who suffer, as neighbors, friends, relatives or with those who live complex experiences, situations and disadvantages from the point of view. In view of health and finance, they promote activities such as so-called "suspended expenses." Solidarity activities such as humanitarian aid of any kind or even the simple home delivery of food and medicine for people who do not have the opportunity to go out and meet their needs increase. However, there is a slice of the population that does as empirical evidence in which it has been addressed that physical and psychological distance can modulate the empathic reaction of a person who is observing someone else in pain. So being further away makes the empathic reaction less strong. I think this point is crucial, as this block has forced people to keep their distance, creating a scenario where no one can be close to others and/or you have to wear a mask, which prevents you from feeling the same "level of empathy." However, there is a part of the population that suffers, more than the other, the current situation (social distance, mask, etc.). In this regard, an extremely interesting research by Lomoriello et al. (2018), through empirical evidence, that physical and psychological distance can modulate the empathic reaction of a person who is observing someone else in pain. So being further away makes the empathic reaction less strong. The reference is clearly addressed to the technology that is used, which, even in this phase, depersonalizes relationships on the one hand, or rather distorts them as forced to use them, but brings us closer, albeit virtually, to the other. Humanity finds itself experiencing a kind of hyperconnected feeling in an attempt to mitigate the blow it took when the forced "fence" was declared.

"This evidence provides an important insight into the framework of knowledge on factors capable of shaping empathy, and it is certainly important also in relation to the evidence suggesting a strong link between representations, also in neural terms, of physical and psychological distance. Although it is obvious that in everyday life situations it is not possible to establish in advance the physical distance between an observer and someone subjected to physical pain (given the unpredictability of such situations), the evidence on the importance of physical distance in modulating an empathic reaction could be fundamental for psychotherapy, clinical and medical contexts, in which psychotherapists, doctors and health professionals could use this knowledge to favor or not, as appropriate, an empathic reaction in themselves and in their patients" (Lomoriello et al., 2018, p. 11).

In conclusion, therefore, a strong forcing that could have the effect of withdrawing completely from the other, once the whole virus situation is over. In the worst case, you could see the intensification of some social phobias, the same ones that had previously been alleviated thanks to a simple meeting in the office or on the street. In this moment, even the "how are you" at the beginning of a phone call, video call or conference call is no longer just a formality, as it once was. For example, intelligent workers, discussed in detail in the previous paragraphs, now, when they call their collaborators, must expect after the usual question, not a simple "good," but much more complex answers. Generating in those who receive the request the false belief that the other is actually interested in their situation. While those who pose it could generate anxiety and anguish given the obligation to listen, feeling almost obliged, to the answers that the other person is giving. Thus, it can be thought that the situation of the aforementioned "forced empathy" may occur. This is because the distance and the emergency situation make people want to be heard and appreciate "how are you?" the hook to express fears, emotions, fears and weak points (Pasetti, 2020).

DISCUSSIONS

Each nation is facing the emergency from a different starting condition that will inevitably affect the timing and methods of recovery.

It is not yet possible to predict if, how and when Italy will rise, but what is not hoped for is a return to normality. That normality in which every day individuals have to fight to improve their conditions, of life and work, and to ask, at most, when they do not have to defend those who have been conquered by centuries of social struggles, for greater rights. The crises faced so far and the recipes adopted to overcome them do not lead us to hope to be able to build a better, more just, more favorable, less unequal world, but once again to see wages decrease, precariousness increase, go backwards, poverty and unemployment reach historic highs. This time it will not be the army that will stop the cry of despair that rises from the world, but an invisible threat that stands between individuals and keeps them separate, everyone will be more committed to defending themselves from the other and they do not have the strength to defend themselves together. It is all that humanity does not hope for.

CONCLUSION

To conclude, referring above all to the latest developments with the OpenFiber agreement in Italy, the political question underlying the problems due to connectivity is of long standing. Even today we can see the duality of Italy, on the one hand the one characterized by super-speed and hyper-connection, on the other the one that has network infrastructural deficiencies (total absence of connection) and that struggles to have a stable connection. All this translates into an economic delay for the entire country, mainly due to the lack of growth opportunities that today, more and more, pass through the network. With the hope that the OpenFiber project, approved by the government, can really solve one of the biggest problems and that this can slightly reduce the gap with the whole of Europe. Furthermore, the Covid-19 crisis phase has brought out with greater force the work problems already present in previous years. In particular, following the lockdown phase, it emerged that the continuous cuts made to funds destined for universities, research and healthcare, have led to a structural and organic deficiency that has generated deep micro-crises within the crisis itself. Therefore, the hope is that Covid-19 will serve as a lesson and that more funds will be allocated to sectors that are objectively fundamental for society.

AUTHOR CONTRIBUTIONS

VA and CI conceptualized the contribution. VA wrote the paper. CI reviewed the manuscript and provided the critical revision processes as PI. All authors approved the submission of the manuscript.

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BRIEF RESEARCH REPORT
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Fear of Virus or of Competitors? The Decision Rationales of Financial Managers Under COVID-19

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This paper surveyed 422 financial managers before the number of novel coronavirus (COVID-19) infections in China peaked and used path analysis to study the risk decision-making mechanisms of financial managers. The study found that whether financial managers developed coping strategies depends on their assessment of potential business revenue losses. There are two transmission paths: the direct effect refers to the risk perception directly caused by COVID-19, while the indirect effect refers to managers' fear that they will not make timely adjustments or will make judgment errors, resulting in the loss of competitive advantage. It is worth noting that the indirect effect exceeds the direct effect, which indicates that financial managers are more rational than ordinary people in dealing with COVID-19, that they are relatively more concerned about competitor changes, and that they may even view COVID-19 as an important opportunity to obtain a better competitive position.

Keywords: novel coronavirus (COVID-19), financial managers, decision-making, competitors, China

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INTRODUCTION

The novel coronavirus (COVID-19) pandemic broke out at the end of 2019 and has shown a trend of development worldwide. The spread of infectious disease rumors through social networks has been shown to cause public mood swings (Smith and Christakis, 2008; Hill et al., 2010) and can even affect people's behavior, such as their cooperative behavior (Nowak and May, 1992; Ohtsuki et al., 2006). Rumors about infectious diseases will form an "emotional contagion" (Hatfield et al., 1994) in a short period of time and affect family relationships (Larson and Almeida, 1999), roommate relationships (Howes et al., 1985), and teammate relationships (Barsade, 2002), and even lead to large-scale emotional contagion via social networks (Kramer et al., 2014). This negative emotional contagion has been shown to cause significant economic damage. For example, overreaction of the government during the Southeast Asian respiratory syndrome led to a decline in the Asian tourism industry (Hai et al., 2004; McKercher and Chon, 2004), and fear and panic sentiments caused short-term damage to the Hong Kong economy (Siu and Wong, 2004). During the Southeast Asian crisis, some studies argued that the primary reason for the crisis was a sudden shift in market expectations and confidence (Feldstein, 1998; Radelet and Sachs, 1998; Stiglitz, 1999; Park and Song, 2001).

Emotional contagion also has a direct impact on professionals' work emotions. Bartel and Saavedra (2000) studied the moods of 70 working groups and found that they could be divided into eight types of emotions and that the differentiation of work emotions is

related to task and social interdependence, membership stability, and mood regulation norms, as well as others. Experiencing positive emotional contagion led to improved cooperation, decreased conflict, and increased perception of task performance (Barsade, 2002). Emotional contagion also affects a person's social judgment (Doherty, 1998), affects leadership and job output (Johnson, 2008), affects gender differences (Doherty et al., 1995), and influences product attitudes (Howard and Gengler, 2001). Nofsinger (2005) argued that the general level of optimism or pessimism in society is reflected in the emotions of financial decision-makers. Social mood determines the types of decisions made by consumers, investors, and corporate managers alike. Extremes in social moods are characterized by optimistic (pessimistic) aggregate investment and business activity.

Most research on the impact of infectious diseases on the emotions is aimed, for the most part, at the public level and little attention is paid to the management community, especially financial managers. Emotional contagion of financial managers might be transmitted to financial markets and cause volatility. COVID-19 is a physical health threat to financial managers so it will also impact their investment decisions, which might further affect the volatility of financial markets. Financial managers are usually better at handling events involving risk than ordinary people. They also communicate through the industry community to make the most reasonable judgments regarding risks. There are two paths in this decision-making process: on the one hand, financial managers are worried about the impact of COVID-19 on their own organization's business; on the other hand, they are also worried about their own relative competitiveness due to decision-making errors. By analyzing the occurrence mechanism of these two paths, it is helpful to understand how the risk of COVID-19 influences fluctuations in the financial market through the decision-making mechanism of financial managers. This paper investigates 422 financial managers in China and uses path analysis to explore the internal logic of the aforementioned decision-making mechanism.

METHOD

The survey was conducted between February 23, 2020, and February 25, 2020, when the number of COVID-19 infections in China had not yet peaked and the disease had only just begun to spread globally, which led to increasing risks in the financial markets. Conducting a survey at this stage enabled us to obtain a more realistic perspective on financial managers' perception of risks.

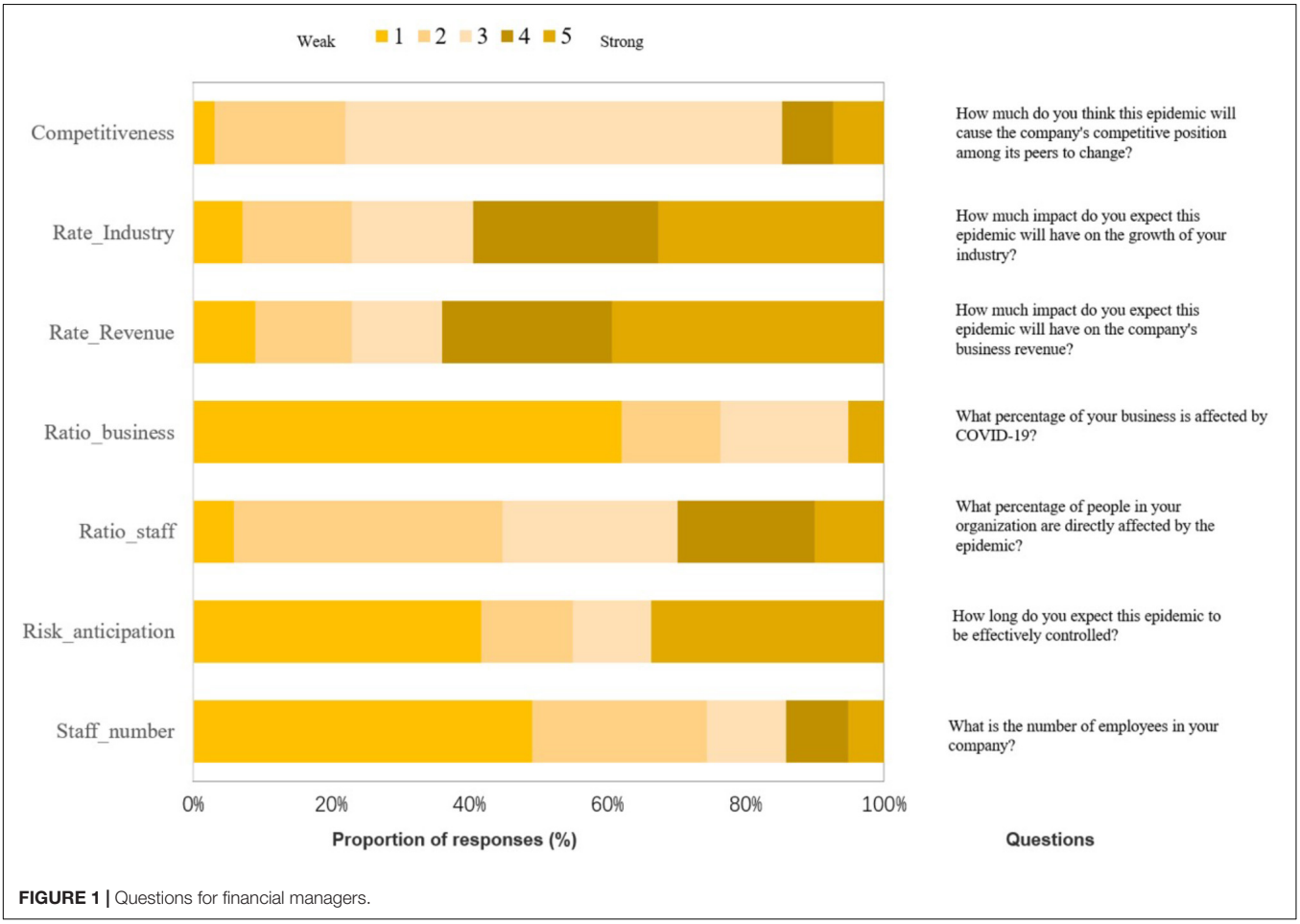

FIGURE 1 | Questions for financial managers.

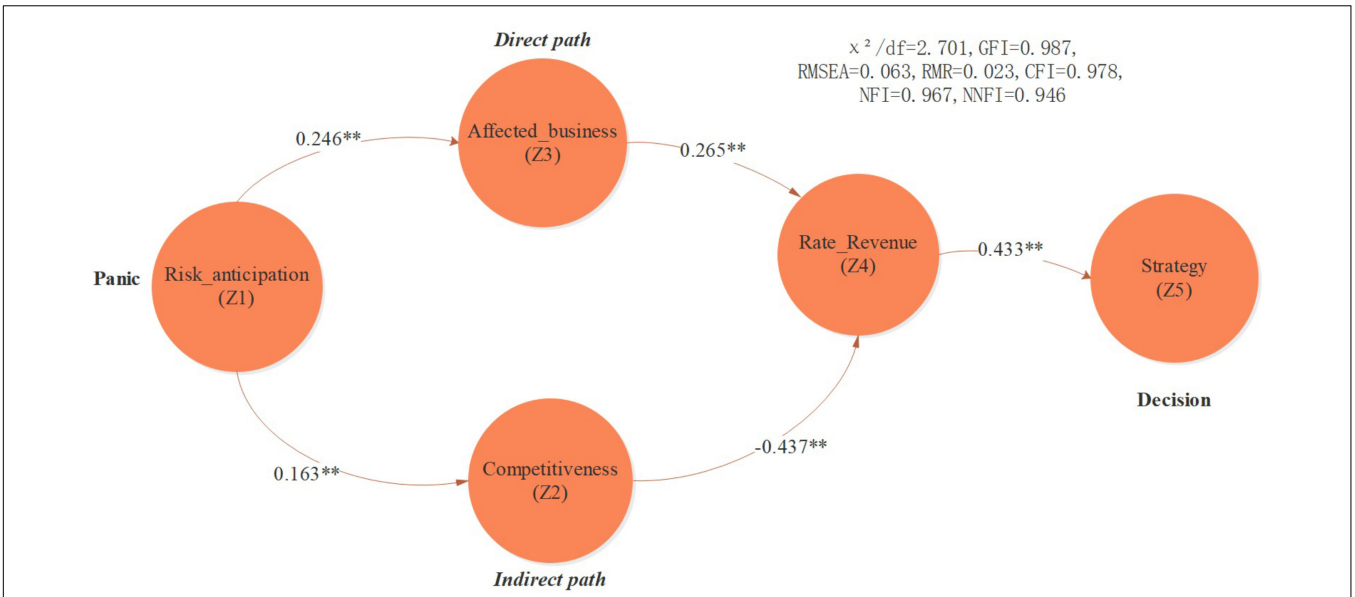

FIGURE 2 | Path analysis results. Note: → indicates the path influence relationship, $^{*}p < 0.05$, and $^{**}p < 0.01$.

The survey was conducted using a questionnaire, which featured eight questions (see **Figure 1**). We first interviewed 10 managers by phone to learn about their judgments on the COVID-19 trend, the impacts on the company's business, and the measures they took. Based on these interviews, we compiled an initial questionnaire and collected 30 samples. After analyzing the samples, we adjusted the questions and finally produced a questionnaire with eight questions. In the face of the COVID-19 outbreak, not all financial managers developed a comprehensive epidemic response strategy, so Question 8 was used to investigate whether they specifically developed a COVID-19 response plan (yes or no). The other seven questions were asked to investigate their risk perception (using a five-point scale). Based on the collected data, this paper used the path analysis model to analyze the financial managers' decision-making logic regarding pandemic risk perception and in formulating their response strategy.

The path regression model is defined as (**Figure 2**):

$$Z_2 = p_{12} \times Z_1$$
$$Z_3 = p_{13} \times Z_1$$
$$Z_4 = p_{24} \times Z_2 + p_{34} \times Z_3$$
$$Z_5 = p_{45} \times Z_4$$

Z_1, Z_2, Z_3, Z_4, Z_5 represent decision variables, p_{ij} represents path coefficients.

RESULTS

The questionnaire was distributed randomly throughout associations in the financial industry, and a total of 422 valid responses were collected. The managers surveyed had more than 5 years of experience in the industry and often participated in events organized by industry associations. Among them, 64.93% of managers (n = 274) had previously formulated an outbreak response plan. Both the Kolmogorov–Smirnov test and the Shapiro–Wilk test were significant at a 1% level ($p < 0.01$), indicating that the data conformed to the characteristics of a normal distribution. In order to further analyze the financial manager's decision-making mode when faced with epidemic-related risk, this paper used path analysis methodology to study the interrelationship between various factors. **Figure 2** illustrates the path analysis chart and **Table 1** demonstrates the path coefficients and fitting indicators. The MI values are far below 20 and the fitting indicators are also good

$$\left(\begin{array}{l}\chi^2/df = 2.701,\ GFI = 0.987,\ RMSEA = 0.063,\\ RMR = 0.023,\ CFI = 0.978,\ NFI = 0.967,\ NNFI = 0.946\end{array}\right),$$

TABLE 1 | Regression—MI table.

X	→	*Y*	MI	Par change
Rate_Revenue	→	Affected _business	1.024	−0.214
Strategy	→	Affected_business	9.579	−0.372
Strategy	→	Rate_Revenue	3.313	0.403
Risk_anticipation	→	Rate_Revenue	1.024	0.051
Rate_Revenue	→	Competitiveness	1.024	0.332
Strategy	→	Competitiveness	0.130	−0.036
Affected_business	→	Strategy	8.942	−0.062
Competitiveness	→	Strategy	0.095	0.009
Risk_anticipation	→	Strategy	0.055	0.005
Rate_Revenue	→	Risk_anticipation	1.024	0.051
Strategy	→	Risk_anticipation	0.340	0.068

→ *indicates the path influence relationship.*

which indicates that the path analysis model features good explanatory power.

DISCUSSION

According to **Figure 2**, there are two significant paths that affect the manager's decision-making process: the direct path and the indirect path. Faced with the uncertainty of COVID-19, whether a manager develops a coping strategy depends on their individual assessment of business revenue loss potential; their judgment is moderated by these direct and indirect effects. The direct effect refers to the risk perception directly caused by COVID-19, which is usually derived from the manager's direct observations and risk expectations of infectious disease, by assessing the scope and duration of the epidemic's spread. The indirect effect refers to managers worrying that they did not make timely adjustments or misjudged the situation, which might result in the loss of advantage amid fierce competition. Anxiety regarding the aforementioned two risks is the main reason that financial managers make decisions. The direct effect might cause managers to underrecognize or overreact to risks, while the indirect effect plays an intensification role, further contributing to managers' panic.

Interestingly, the coefficient of the direct effect was 0.0652 (Risk_anticipation → Affected _business → Rate_Revenue), which was less than the coefficient (0.0712) of the indirect effect (Risk_anticipation → Competitiveness → Rate_Revenue), indicating that the indirect effect exceeded the direct effect. This might imply that financial managers are more rational than ordinary people when dealing with COVID-19, that they are more concerned about competitor dynamics, or that they might even view COVID-19 as an important opportunity to adjust their competitive position. This paper's research results demonstrate that different communities feature significant differences in their perception of risk and behavioral patterns in terms of COVID-19. Evidence from financial managers can enable a better understanding of the potential impact of infectious disease risk on financial markets.

DATA AVAILABILITY STATEMENT

The datasets for this article are not publicly available because the data is only authorized for this study. Requests to access the datasets should be directed to the corresponding author, BC.

ETHICS STATEMENT

The studies involving human participants were reviewed and approved by Central University of Finance and Economics. Written informed consent to participate in this study was provided by the participants.

AUTHOR CONTRIBUTIONS

JS was responsible for the overall research ideas, model design, and thesis writing. TW was responsible for document review writing and data collection and processing. BC was responsible for model optimization and discussion of research conclusions. All authors contributed to the article and approved the submitted version.

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BRIEF RESEARCH REPORT
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Intervention and Improved Well-Being of Basic Science Researchers During the COVID 19 Era: A Case Study

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The coronavirus disease-19 (COVID-19) pandemic has affected individuals of all categories, irrespective of their geographical locations, professions, gender, or race. As a result of full or partial lock-down and stay-at-home orders, the well-being and productivity of individuals were severely affected. Since basic science research requires laboratory experiments, the work-from-home strategy hurt their productivity. In addition, the combination of decreased productivity and staying at home is likely to compromise their well-being by causing stress and anxiety. In this case study, a strategy was developed to engage researchers through listening and learning, motivation, and empowerment, using regular virtual sessions. Through these virtual sessions, research work was prioritized and coordinated, from idea conception to writing research papers and grant proposals. Perceived stress scores (PSS) and COVID-19-related stress (COVID-SS) scores were measured to evaluate general and COVID-19-induced stress, respectively, every month from March to July 2020 during the COVID-19 era. The result showed a significant improvement in both the PSS and the COVID-SS scores of the intervention group compared to the control group. In addition, while there was no/minimal change in PSS and COVID-SS scores from March to subsequent months until July for the control group, the intervention groups showed significant and consistent improvement in both scores in the intervention group. Overall, the intervention strategy showed improved well-being for basic science researchers, which was also consistent with their improved productivity during the COVID-19 era.

Keywords: COVID-19, productivity, perceived stress score, laboratory research, well-being

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INTRODUCTION

The coronavirus disease-19 (COVID-19) pandemic is an ongoing world crisis. This pandemic has taken a toll on human health and has also placed a huge burden on economies, societies, and families across the globe (Carter et al., 2020; Cutler, 2020; Donthu and Gustafsson, 2020; Hua et al., 2020; Jenson, 2020; Mclaren et al., 2020; Ornell et al., 2020; Power, 2020; Satiani et al., 2020). This COVID-19 crisis is further deepened because the future of countries, societies, and individuals is

uncertain and unpredictable in the months and perhaps years to come. A recent special issue on COVID-19 by "Taloy and Francis" describes the impact of this pandemic on, "Emerging markets finance and trade," which ultimately causes stress in world economies and societies (Taylor and Francis, 2020). In addition to the impact on world economies, world trade has experienced a massive contraction as a result of a drastic reduction in trade connectivity and commercial activities among countries during COVID-19 outbreak (Vidya and Prabheesh, 2020). The trade forecast among the major trading countries further Shows a decline until December 2020. However, it is worth mentioning that amid the COVID-19 pandemic, there is a significant improvement in air quality, though temporarily, and a positive macroeconomic response has been seen in some countries such as China and India during the COVID-19 outbreak (Ming et al., 2020). The impact on global economies and loss of millions of jobs have been one of the major causes of stress and anxiety among global populations.

The impact of the COVID-19 pandemic on human health, which caused ∼38 million infections and >1 million deaths world-wide as of October 15, 2020, far exceeds the impact of previous epidemics or pandemics in recent history (Coronavirus-Resources-Center, 2020). Although over 90% of people recovered from the infection/disease, many individuals suffered from multiple organ damage (lungs, kidney, liver, heart, etc.) (Renu et al., 2020; Spuntarelli et al., 2020). Further, a large number of recovered populations from COVID-19 also suffered from mental and psychological diseases/conditions such as stress, anxiety, and depression (Salari et al., 2020; Xiong et al., 2020). Studies have shown that ∼50% of individuals who recovered from COVID-19 are diagnosed with depression, and ∼40% are diagnosed with anxiety and stress (Rogers et al., 2020). Individuals associated with COVID-19 patients, and others, especially those who have lost their jobs and are experiencing financial crises, also show symptoms of depression, anxiety, and stress (Dubey et al., 2020; Titov et al., 2020).

This is the first time in modern history that almost all countries, either fully or partially, enter into a lock-down phase and enforce stay-at-home orders (Asensio et al., 2020). One of the major health concerns, as a result of lock-down and stay-at-home orders, is the mental health of individuals who stay at or work from home (Killgore et al., 2020). Stress and anxiety are usual reactions to any unpredictable pandemic situation. As a result of stress due to the COVID-19 pandemic, the general population, particularly health care professionals and college students, experienced changes in concentration, anxiety, irritability, and eventually reduced productivity (Tangen et al., 1981; Kecojevic et al., 2020; Ozamiz-Etxebarria et al., 2020; Stanton et al., 2020; Wu et al., 2020). These studies suggest a need to develop mitigation and psychological intervention strategies that can improve the mental health of the general population during the COVID-19 era, especially in vulnerable groups such as health professionals and college students. To the best of our knowledge, there is no study conducted among basic science researchers to examine the impact of the COVID-19 epidemic on psychological health and stress or the relationship of these factors to productivity. Therefore, we conducted a case study on intervention and well-being of basic science researchers at the University of Tennessee Health Science Center (UTHSC).

Research laboratories at UTHSC were closed for all non-emergency work in March, and the researchers were asked to work from home (UTHSC, 2020). Although manuscripts and grant writing could be done from home, it is very difficult to stay productive if experiments in the basic science laboratory are completely stalled. Basic science experiments take 1–2 weeks to wrap up and equally the same time to restart. Thus, until the research laboratories partially opened in the first week of June, employees had lost 3 months of complete followed by 2 months (June–July) of partial basic science research. In addition to reduced productivity, the work-from-home plan for researchers who normally work in a laboratory setting can increase stress and anxiety. Compounded by COVID-19-related stress, this has the potential to further reduce productivity. Moreover, due to uncertainty surrounding lab reopening dates, researchers were also uncertain about their career progression. All these factors may contribute to a lack of concentration, irritability, insomnia, and reduced productivity among scholars.

The objective of the present study is to design an interventional strategy to mitigate stress and maintain well-being and productivity for basic science researchers during the work-from-home order in the COVID-19 era. The mitigation strategy is to plan and implement necessary experiments during the pre-lock-down period, followed by engaging in idea development, data analysis, and manuscript writing, as well as engaging in listening and empowering sessions via virtual lab meetings during and after the lock-down periods. The hypothesis is that the interventional strategy will significantly reduce stress and improve the well-being of basic science researchers while maintaining their productivity. To assess the well-being of subjects, Perceived Stress Score (PSS) and COVID-19-related stress scores (COVID-SS) were measured. Generally, the stress levels of health care professionals and college students are measured using the PSS method (Du et al., 2020; Georgiou et al., 2020; Guo et al., 2020; Meira et al., 2020; Zarghami et al., 2020), which is the most widely used method to monitor perceived stress (New Hampshire Department of Administrative Services, 2020). However, to measure the stress, anxiety, and overall well-being of individuals specifically induced by COVID-19-related changes in lifestyle and altered productivity, the PSS method may not be sufficient. Therefore, we used the COVID-19 stress related score (COVID-SS) to assess the fear, learning, and growth in knowledge of individuals during the pandemic (Epilepsy Society, 2020). The current study results suggest an improved well-being of the intervention group compared to the control group, which is also consistent with the reduced stress and improved productivity of the intervention group.

METHODS

Preparation Before the Crisis for Intervention Group

When the WHO declared COVID-19 a Public Health Emergency of International Concern on 30 January 2020 (Patel et al., 2020),

a strategic plan for researchers in our group was put-together. The strategic plan included: (1) postponing manuscript writing and other paper work and performing wet-lab experiments to obtain data until the lab was closed in the second week of March, (2) data analysis and manuscript writing during the work-from-home orders from mid-March to May 31 and until July 31 during partial lab-closure, (3) conceiving new ideas and writing manuscripts for review papers, as well as writing grant proposals for the same periods. To make the researchers accountable for their productivity, a 2 h virtual lab meeting every Monday and one-on-one virtual meetings as needed were implemented. The demographics of the intervention group was 4 men and 5 women that included 3 students, 2 post-doctorate fellows, 3 research staffs, and 1 faculty. The study population was generally healthy and their age ranged approximately from 22 to 50 years. Since the intervention requires a certain supervisory relationship among all participants, it is not feasible to increase group size. Inviting researchers from other research groups may result in a conflict of interest among principle investigators since most research groups are independent. Hence, we could include only nine people in the intervention group.

Implementation During the Crisis

A modified anonymous strategy was used as an intervention. Almost half of each lab meeting until May 31 was spent in listening to everyone's concerns, celebrating any good news, and COVID-19-related facts from reliable sources. The frequency of these discussions was reduced when the laboratory was partially opened from June 1 to July 31. In general, the strategy was to learn from each other and empower each other. During the laboratory meetings, some engaging games were also played to overcome stress. The empowering sessions were developed based on vast knowledge, emotional intelligence, and the experience of our diverse group, as well as available literatures (World Health Organization, 2004; Shultz et al., 2016; Hendriks et al., 2017; Seyedin et al., 2019; Jiménez et al., 2020; Schlesselman et al., 2020). We compiled the following discussion topics to empower each other.

(1) COVID-DIFFERENTIATOR (COVID-DIFF): Similar to any crisis, COVID would differentiate people into three categories: (1) Individuals who were negatively impacted (with no mistake of theirs), (2) individuals who stayed the course and were able to handle well, and (3) individuals who found new opportunities and improved performance. In general, most people, including our study participants, belong to categories 1 and 2. Our goal was to empower them with the below mentioned strategies, which could help them to move to category 3.
(2) Faith/dreams vs. Panic/fear: The intervention group discussed the pros and cons of having faith/dreams vs. feeling panic/fear, with numerous examples. These empowered each other to have faith and dreams.
(3) Facts/reality vs. Opinion/hype: The intervention group was advised to follow facts and reality and educate others with these rather than uncorroborated opinions and hype.
(4) Safety vs. Carelessness: The intervention group was educated to exercise safety and caution by following the COVID-19 policies and guidelines of national and local organizations.
(5) Managing the crisis vs. Getting under the crisis: The intervention group discussed various aspects of the crisis and how one can manage the crisis, rather than getting under the crisis, in a way that negatively impacts us.
(6) Thriving vs. Surviving: Finally, the intervention group discussed how to thrive during the crisis and not just survive. As Stanford economist Paul Romer once stated, "a crisis is a terrible thing to waste" (Chisholm-Burns, 2010). The intervention group as a whole decided, "we will not let the crisis go to waste." The group discussed various ways to improve productivity and manage stress during the crisis. For example, ways to improve grit and mental toughness by acquiring positive attitudes and self-discipline were discussed. Besides, performing physical and mental activities, such as walking/running/exercising, yoga, and meditation were promoted in group discussion.

In addition to the above empowering sessions, the intervention group also discussed the following advantages of working from home.

(1) Freedom: freedom to work with a chosen time, place, and uniform.
(2) Family together: opportunity to spend quality and quantity time with families.
(3) Time to think creatively: compared to lab and office environments, work-from-home may give a change in environment, more time, and quietude to think creatively.
(4) Yoga and Meditation: a home environment may empower people to do yoga and meditation to maintain physical and mental health.
(5) Opportunity to take care of the backlog, start new writing projects, and contribute to society: working from home may give more time for data analysis, writing manuscripts, and initiating new projects for review papers and/or grant proposals. It can also motivate and empower society, which is going through a difficult time, through messages via reliable sources.

Finally, as a group and as individuals, the intervention group did reflection exercises on the following things. (1) How have I contributed positivity or negativity to others? (2) Does someone feel better after an interaction with me vs. how they felt before? (3) Did shared interest rise above self-interest? (4) Did I listen more – or talk more? (5) How many times today did I complain about someone or something? (6) How many times did I simply say thank you? (7) What did I learn this week, especially that challenged my thought processes? (8) What did I do this week, especially that is unique and out-of-norms?

Control Group

A control group of UTHSC basic science researchers, which did not go through the intervention as described above, is included in this study. The control group consists of 6 students,

3 post-doctorate fellows, and 1 research scientist (5 men and 5 women). The participants were generally healthy and their age ranged approximately from 25 to 40 years. The control group of basic science researchers also went through similar challenges at UTHSC due to complete lab-closure from mid-March to May 31 and partial lab-closure from June 1 to July 31.

OUTCOME MEASURES

Two outcomes were measured during the 5-month period. The PSS and COVID-SS outcomes were measured by using their respective surveys upon an Institutional Review Board (IRB) approval from the University of Tennessee Health Science Center.

Perceived Stress Score (PSS)

The PSS of nine participants from the intervention group and ten participants from the control group for the months of March–July were measured, upon their consent to do a volunteer survey. PSS is the most-widely used method to measure stress levels in occupational health, especially among professional students in health science. This method was essentially used as described (New Hampshire Department of Administrative Services, 2020). In brief, PSS was measured by self-scoring the following questions. Scoring was performed (between 0 and 4; 0 being never and 4 being very often), followed by reversing the scores of questions 4, 5, 7, and 8, and then adding all the scores. Scores with 0–13, 14–26, and 27–40 are defined as low, moderate, and high stress, respectively. The group PSS scores were then analyzed longitudinally for the months of April–July, using March as control month, as the intervention began in April. COVID-SS scores for the intervention group were also compared and analyzed from the control group for each month.

COVID-19-Related Stress Scores (COVID-SS)

The COVID-SS of nine intervention participants and ten control participants for the months of March–July were also measured upon their consent to do a volunteer survey. COVID-SS is a new method that used to assess the stress level of participants during the COVID-19 era using their behaviors and actions in three zones (fear, knowledge, and growth). This method was essentially used as described previously (Manch, 2020). In brief, the questions/statements, as presented in **Table 1**, were used to self-assess the three zones: fear, knowledge, and a growth mindset. Every correct statement for each zone carries one point. The total points for each zone represent the mindsets and attitudes of participants in terms of COVID-19-related fear, knowledge, and growth. The information obtained from these zones can then be correlated with COVID-19-induced stress and overall well-being of participants. The group COVID-SS scores were then analyzed longitudinally for the months of April-July, using March as the control month, as the intervention began in April. The COVID-SS scores for the intervention group were also compared and analyzed from the control group for each month.

TABLE 1 | Statements used to score COVID-SS for each zone. Each correct statement carries 1 point.

Fear zone (total 5 points)	Knowledge zone (total 7 points)	Growth zone (total 8 points)
I grab food, medications, and toilet paper that I don't need	I start to give up what I can't control	I think of others and know how to help them
I spread emotions related to fear and anger	I stop consuming what hurts me, from food to news	I make my talents available to those who need them
I complain frequently	I identify my emotions	I live in the present and focus on the future
I forward all messages I receive about COVID-19	I am aware about the situations and know how to act	I am empathetic to myself and to others
I get mad easily	I evaluate information before spreading false	I thank and appreciate others
	I recognize that we all are trying to do our best	I keep a happy emotional state and give hope
		I look for a way to adapt to changes
		I practice quietude, patience, relationships, and creativity

Research Productivity

Our mitigation and empowering strategies were likely to improve the research productivity. It was measured only in our intervention study group in terms of conceiving ideas, data analysis, manuscript writing and submission, manuscript acceptance, and publication, as well as grant submission.

Statistical Analysis

Mean ± SEM was calculated and compared to the control group. Student's *T*-test was applied to compare the scores between the intervention and control groups, as well as between the control month (April) and individual intervention months (April–July) for both control and intervention groups. All the statistical calculations were performed using GraphPad Prism 7. $p < 0.05$ was considered statistically significant.

RESULTS

Perceived Stress Score (PSS)

An intervention group of nine participants and a control group of ten participants volunteered to take the perceived stress test, as described in the outcomes measure section. The Mean ± *SD* of the PSS were evaluated, and the relative scores of the intervention group vs. control group were analyzed. Comparison and analysis were also performed in a longitudinal manner, in which March was a control month when the intervention began (**Figure 1**). Overall, results showed a relatively high PSS (17.4 ± 2.7) for the intervention group in March, which consistently decreased in the subsequent months, with a statistically significant decrease in June (13.8 ± 2.3) (**Figure 1A**). However, the PSS scores did not significantly change in the

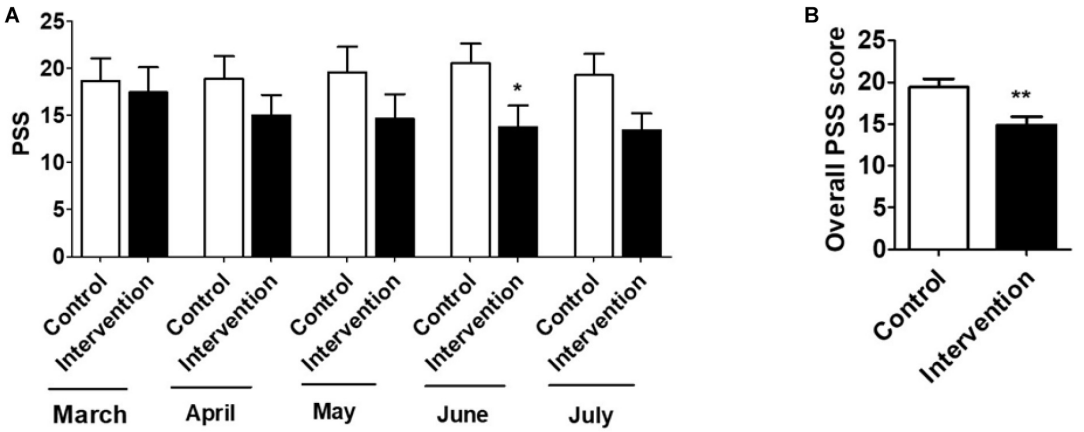

FIGURE 1 | (A) Mean ± *SD* of Perceived Stress Score (PSS) of control (n = 10) and Intervention (n = 9) groups for March to July. **(B)** Mean ± *SD* of overall PSS of control (n = 50, 10 subjects for 5 months) and intervention (n = 45, 9 subjects for 5 months) groups. *T*-test was applied to compare the scores between intervention and control groups. $p < 0.05$, $p < 0.01$ are represented as "*" and "**", respectively when compared the scores between intervention and control groups. "#" represents $p < 0.05$ when compared between intervention groups (March vs. other months). "$" represents $p < 0.05$ when compared between control groups (March vs. other months).

control group from the months March to July. Importantly, there was a statistically significant decrease in the overall PSS scores (March-July combined) of the intervention group compared to the control group (14.7 ± 0.8 vs.19.3 ± 0.3) (**Figure 1B**). In general, the intervention group showed an increased stress level (moderate stress) in March, which was subsequently decreased to low stress in the subsequent months. However, the stress level in the control group remained moderate throughout these 5 months. Since the PSS method is used to measure general stress levels, in the following section we used COVID-19-related stress scores in our participants and determined whether intervention group had a significantly different stress level.

COVID-19-Related Stress Scores (COVID-SS)

COVID-SS measures three different components (fear, knowledge, and growth zones) as described in the outcomes measure section. This method was used specifically to measure COVID-19-related stress and anxiety. COVID-SS examines whether participants can change their behavior and actions as a result of training and move from the fear zone to the knowledge zone, and ultimately the growth zone, across the 5 months. Nine participants from the intervention group and ten participants from the control group took the COVID-19-related stress test survey. The Mean ± *SD* of COVID-SS was evaluated for each zone during the months of March–July. The results from nine intervention participants showed a relatively high COVID-SS for the fear zone (1.78 ± 0.52) in March, which subsequently decreased in April, with a statistically significant decrease in May (0.33 ± 0.23), June (0.55 ± 0.24), and July (0.33 ± 0.23) (**Figure 2A**). On the other hand, the COVID-SS for the knowledge zone steadily increased from March to July, with a statistically significant increase in May (5.23 ± 0.23), June (5.33 ± 0.37), and July (5.66 ± 0.37) compared to March (3.33 ± 0.47) (**Figure 2C**). Similarly, the COVID-SS for the growth zone also steadily increased from March to July, with a statistically significant increase in May (6.67 ± 0.41), June (7.01 ± 0.16), and July (7.10 ± 0.26) compared to March (4.44 ± 0.62) (**Figure 2E**). On the other hand, compared to march, COVID-SS scores of the control group in the fear zone did not statistically change in the subsequent months (**Figure 2A**). However, compared to March, COVID-SS scores in July significantly increased in both knowledge (4.80 ± 0.49 vs. 1.27 ± 0.42) (**Figure 2C**) and growth (6.01 ± 0.75 vs. 2.26 ± 0.75) zones (**Figure 2E**), perhaps due to partial opening of the lab. However, this increase in the knowledge and growth zones for the control group was relatively lower than that of the respective increase in the intervention group.

More importantly, COVID-SS scores of the intervention group in the fear zone were significantly lower than the control group in May (0.33 ± 0.22 vs. 1.47 ± 0.49) and July (0.33 ± 0.33 vs. 1.65 ± 0.55) (**Figure 2A**). On the other hand, COVID-SS scores of the intervention group in knowledge zone were significantly higher than the control group in May (5.33 ± 0.23 vs. 1.13 ± 0.38) (**Figure 2C**). Similarly, COVID-SS scores of the intervention group in growth zone were also significantly higher than the control group in May (6.67 ± 0.47 vs. 1.95 ± 0.65) and June (7.01 ± 0.16 vs. 1.90 ± 0.63) months (**Figure 2E**). We also analyzed the overall COVID-SS scores for each zone for the months of March-July for both intervention and control groups. The overall COVID-SS scores of the intervention group in the fear zone were significantly lower than the control group (0.75 ± 0.26 vs. 1.74 ± 0.08) (**Figure 2B**). On the other hand, the overall COVID-SS scores of the intervention group in the knowledge zone were significantly higher than the control group (4.80 ± 0.43 vs. 4.18 ± 0.21) (**Figure 2D**). Similarly, overall COVID-SS scores of the intervention group in the growth zone were also significantly higher than the control group (6.13 ± 0.51 vs. 4.88 ± 0.40) (**Figure 2F**). Taken together, these findings

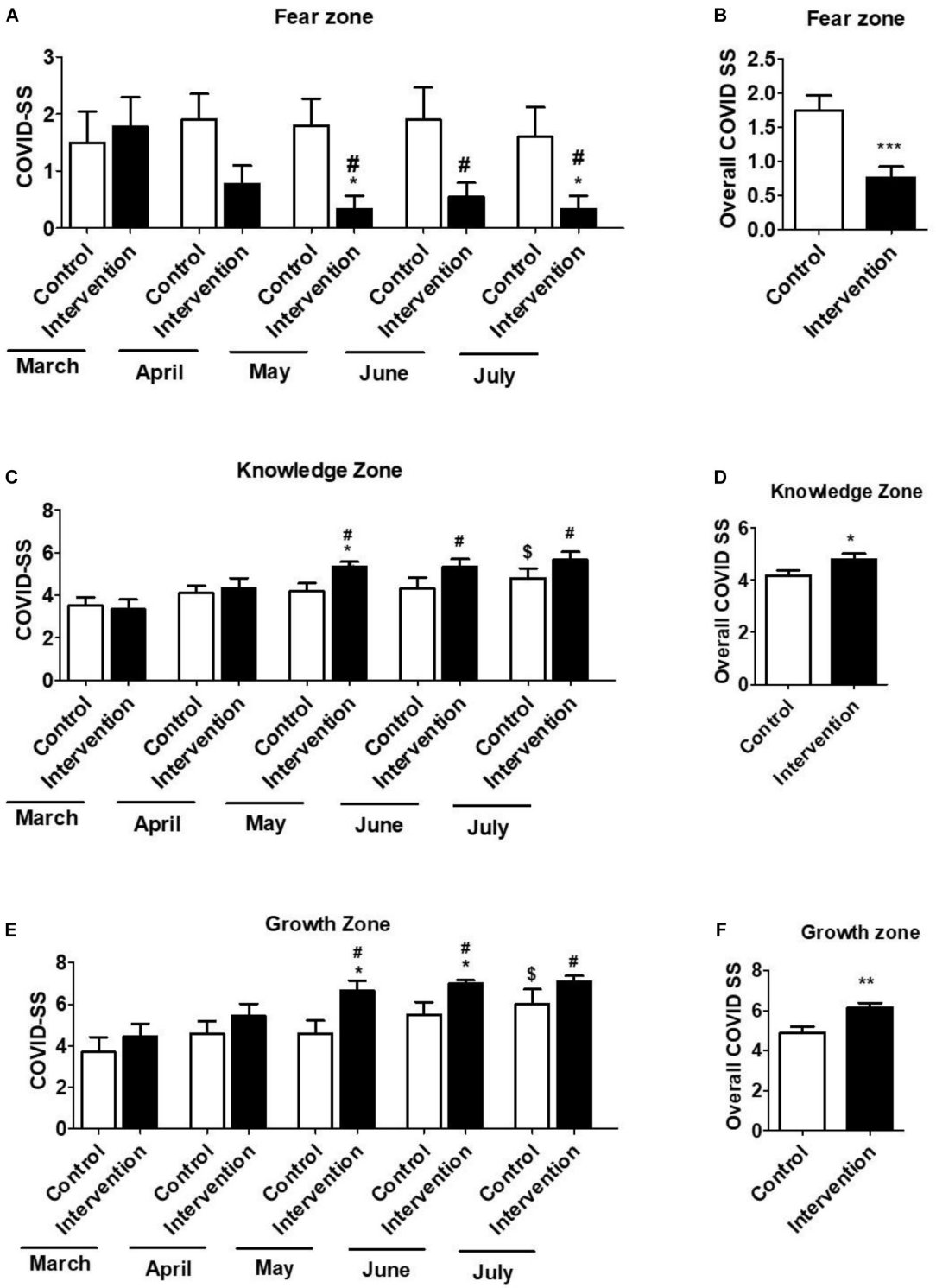

FIGURE 2 | The COVID-related stress score (COVID-SS) in the fear zone **(A,B)**, knowledge zone **(C,D)**, and growth zone **(E,F)** for March, April, May, June, and July were collected and compared between control (n = 10) and intervention (n = 9) groups. The scores of intervention and control groups in March were also compared to their respective scores of intervention and control groups in other months in each zone. The data in **(B,D,F)** represent Mean ± *SD* of overall COVID-SS scores of control (n = 50, 10 subjects for 5 months) and intervention (n = 45, 9 subjects for 5 months) groups. *T*-test was applied to compare the scores between months. $p < 0.05$, $p < 0.01$ are represented as "*" and "**" or "***", respectively when compared the scores between intervention and control groups. "#" represents $p < 0.05$ when compared between intervention groups (March vs. other months). "$" represents $p < 0.05$ when compared between control groups (March vs. another month).

suggest that intervention strategy to deal with COVID-related stress and anxiety significantly and consistently decreased the fear and increased the knowledge and subsequent growth in their knowledge.

Productivity During the COVID-19 Era

It is widely known that reduced stress enhances productivity, and increased productivity feeds into low stress and improved well-being (Anderzén and Arnetz, 2005; Heylighen and Vidal, 2008). Stress and productivity work as a loop that feed into each other. Therefore, the research productivity was measured in terms of conceiving new ideas for a review paper, data analysis for the original paper, and manuscript writing and their publication in peer-reviewed journals. Since the evidence for only published papers can be provided, the productivity metrics for only published papers are presented in **Table 2**. Briefly, the data from a project (**Table 2**) was analyzed, which was later written and published. Two other manuscripts for original articles were also revised and published during the same time-period. In addition to original articles, 7 review papers and 1 editorial were published between March and the first week of September (**Table 2**). Two of these review papers are from the field of COVID-19 for which we conceived the idea of the paper during the COVID-19 era.

For the past 5 years, the average peer-reviewed publication rate for the group is 8 per year. Thus, publishing 11 papers in 6 months can be considered higher than the previous productivity for this research group. It has been widely accepted that obtaining data is the most time-consuming step and requires significant manpower. However, in the absence of experiments, optimal priorities and time management were implemented to maximize productivity with an overall exceptional result. The productivity is also considered unique, since two review articles were published on the much-needed field of COVID-19.

In addition to scientific papers, two opinion columns on COVID-19 were published in the Memphis-based "Commercial Appeal," the "USA Today" network, on April 13 (Kumar, 2020b) and on June 11 (Kumar, 2020a). The former opinion column was on, "University of Tennessee Health Sciences Center making strides in treating COVID-19," in which, a scientific opinion on repurposing antiviral drugs was provided. The latter one was on, "Challenges with COVID-19 could bring transformational change, improve human health," in which, a scientific opinion on how COVID-19 could help improve general immunity and reduce the prevalence of chronic diseases was provided.

DISCUSSION

The present study was designed to mitigate general as well as COVID-19-induced stress in basic science researchers, which subsequently helps to improve the overall well-being and productivity in the intervention group. We used both PSS and COVID-SS methods to measure their stress levels and correlated the improved well-being of the intervention group with their productivity. Overall, findings strongly suggest that the mitigation strategy resulted in reduced stress levels and increased research productivity among basic science researchers during the COVID-19 pandemic. However, the data from the control group suggests that the current COVID-19 pandemic has a significant impact on the mental health of basic science researchers, which is consistent with the impact on mental health in the general population, especially in health care professionals and college students (Tangen et al., 1981; Kecojevic et al., 2020; Ozamiz-Etxebarria et al., 2020; Stanton et al., 2020; Wu et al., 2020).

Overall, the intervention group showed reduced general stress compared to the control group. Our outcome is different from the outcomes derived from the perceived stress and anxiety in the general population, in which this pandemic increased anxiety levels. In one study, high PSS scores among the general population were observed in women, persons under age 30, students, and those who believed themselves to be at a greater risk of contracting the illness (Limcaoco et al., 2020). Additionally, participants' perception of susceptibility to COVID-19 was likely affected by several factors. Participants were not elderly or in other high-risk groups. Further, a certain level of scientific literacy (undergraduate and above) may have equipped the researchers to practice appropriate COVID-related health measures and mitigate COVID-related fear. Moreover, upon comparing with the control group, which were of similar demographics, ages, and education levels, it can be said that the

TABLE 2 | Number of manuscripts written and published during the months of March–July.

PMID/DOI/In press	Type of paper	Idea	Data analysis	Manuscript submission	Revision submission	Published
PMID 32481515	Original article		X	X	X	X
PMID 32443728	Original article				X	X
PMID: 32433651	Original article				X	X
PMID 32696265	Editorial			X		X
PMID 32357553	Review	X		X	X	X
EIDDJ-100021	Review	X		X	X	X
PMID: 32722629	Review			X	X	X
PMID: 32823684	Review	X		X	X	X
doi: 10.1080/23808993.2020.1812382	Review				X	X
PMID: 32842791	Review				X	X
PMID: 32932786	Review			X	X	X

"X" Represent completed task in that particular section.

strategy to deal with stress during the COVID-19 era has helped to manage stress levels of the researchers.

Intervention study based on the psychological health status of researchers as backline workers could provide a potential statewide measure that could be used by other researchers or even frontline workers to cope with stress during the pandemic outbreak. However, stress assessment and outcome measurements used in our study will be more appropriate for stress management and wellbeing of the mental state among researchers. Inconsistent with our findings, the frontline health care professionals, who were working in proximity to patients admitted in the ICU with severe lung infections, experienced mental health problems with substantial psychological distress (Greenberg et al., 2020). A descriptive study that was performed on health care professionals during COVID-19 revealed a relatively moderate level of perceived stress (PSS mean = 15.71 ± 4.02) on PSS-10, along with 38% identified as depressed and 24% as suffering from anxiety. Health care professionals who experience higher perceived stress than others likely worked at intensive care units (ICUs) (Ma et al., 2020). Findings of a meta-analysis indicated a high psychological impact, not only on healthcare workers (HCW) and patients, but also in the general population (Luo et al., 2020; Pappa et al., 2020). The psychological distress was mediated by anxiety and depression. However, the existence of other variables could be wrongly predicted as stress associated with COVID−19.

In a cross-sectional study conducted on frontline nurses (n = 325), 123 nurses were found to have a dysfunctional level of anxiety that involves fear, behavior, and psychological distress (Labrague and De Los Santos, 2020; Lee, 2020). Studies conducted on the psychological impact of COVID-19 on frontline nurses have found an overall high prevalence of anxiety ranged between 18 and 92.3% (Alwani et al., 2020; Luo et al., 2020) that could be averted by providing better organizational and social support, in addition to the implementation of safety measures at the workplace and quality personal protective equipment (PPE) (Labrague and De Los Santos, 2020). Overwhelming workload and lack of sleep may also contribute to the mental burden of frontline workers (Lai et al., 2020) that could be considered during the assessment of their stress levels. In general, healthy people were found to be less affected by COVID-19 related stress compared to those with anxiety-related or mood disorders in the population-based study conducted in the US and Canada (Asmundson et al., 2020). A cross-sectional survey based on modified PSS-10 conducted on 406 individuals comprising professors, students, and health professionals, aimed to assess the prevalence and variables related to perceived stress associated with COVID-19 (Pedrozo-Pupo et al., 2020). In total, 15% of the participants scored for high perceived stress associated with COVID-19. However, the prevalence of high perceived stress was relatively lower than previous studies performed during other epidemics, such as equine influenza (Pedrozo-Pupo et al., 2020). However, psychological responses to epidemics and outbreak management relate to several variables, such as misinformation or information overload and education, although findings regarding education can be inconsistent across different countries. For instance, less educated young people were found more vulnerable to high psychological distress during the outbreak of equine influenza in Australia (Taylor et al., 2008), whereas an opposite trend is seen in China (Qiu et al., 2020). Since PSS data is a test for well-being in general conditions, and it may be biased for stress induced by COVID-19, another method that measured COVID-SS was used.

The present study findings suggest that the intervention strategy to deal with COVID-related stress and anxiety significantly and consistently decreased the fear and increased the knowledge and subsequent growth in their knowledge. This is a new test that used for the first time to evaluate fear, knowledge, and growth mindsets in researchers during the COVID-19 era. Thus, it is not feasible to directly compare these outcomes with others in the literature that used different tests. This outcome measurement was used specifically in the context as an innovative strategy to help manage stress and increase productivity among researchers. Recent studies evaluated mental health associated with COVID-19-mediated stress and anxiety in the general population (Liu et al., 2020; Shammi et al., 2020), as well as in health workers who were involved in the treatment of COVID-19 patients (Bohlken et al., 2020; Yin et al., 2020). The outcomes from all those studies showed a significant decrease in their mental health as measured by the prevalence and predictors of post-traumatic stress symptoms (PTSS) and other methods. The participants in those studies experienced high stress and anxiety, lack of sleep, and uncertainty in their future. Thus, unlike other reports, outcomes from the current study with significant improvement in mental health suggest that the strategy to manage the stress of researchers appears to be effective. However, it is important to note that participants were at low risk of becoming unemployed and were not otherwise economically affected by the pandemic. Further, no participants in this study were directly affected by the illness; neither participants nor participants' family members contracted the illness or suffered negative physical health outcomes related to the pandemic, and participants were not in high-risk groups for contracting the disease. In addition, most participants were not directly exposed to sick patients, in contrast with frontline workers. However, it can also be noted that the strategy helped to manage the well-being of the intervention group compared to the control group, which belonged to the same demography, age group, education level, and overall environment.

The United States has been experiencing a surge increase of anxiety prescription drugs in recent decades (Ross et al., 2019). The COVID-19 pandemic may exaggerate stress and anxiety issues in the US. The rationale of the current intervention study aims to provide a proof-of-principle to use anonymous based interventions as an alternative. Both PSS and COVID-SS scores are markers of stress management. It has been reported that group anonymous if performed properly, has the potential to turn negative stress into positive motivations (Murphy Lawrence and Hurrell Joseph, 1987). Anonymous is a widely used therapy method for treatment in alcohol, smoking, and narcotic drug abuse (Moos and Moos, 2006). In this study, the intervention emphasizes positive feedback, encouragement, and mental support to eliminate the fear, stress, and uncertainty due to COVID-19. Improvement in both PSS and COVID-SS scores

from the intervention group, as well as relatively improved scores compared to the control group, proved the general improvement in stress conditions.

It is well-known that increased stress can significantly impair the productivity, and our mitigation strategy has improved the mental health and resulted in improved research productivity during the pandemic. Health and productivity management (HPM) was initially introduced back in the 1990s (Goetzel and Ozminkowski, 2000). The main goal of HPM was to train employees with the capability to handle crises and challenges. Stress management was also introduced at the beginning of the 21st century to promote productivity (Razavi et al., 2012). The COVID-19 pandemic is a challenge for both business and the community. Hence, training researchers to do more with few resources will benefit them in both the short-term and long-term. In the short-term, researchers are engaged in expanding their productivity portfolio by substituting wet-lab research to paper/computer-based research. The paper/computer research conducted during this period, including peer-reviewed articles and review paper writing and white/technical paper publications, are also valuable for their career. More importantly, these works, especially the process of literature research, may provide hints for future wet-lab experiments. It has been widely accepted by scientists that stepping away from the wet-lab allows them to reset and re-think the research plan to come up with more successful ideas (Harrick et al., 1986; De Bloom et al., 2014).

In the long-term, after experiencing these challenges, researchers may be more flexible and mature when facing negative situations. Negative situations include another global pandemic, wars, social conflicts, bias and discriminations, negative research results, and any other situations that may bring stress (Zarei et al., 2014).

STRENGTHS AND WEAKNESSES OF THE STUDY

Our study is unique in that it is designed to maintain well-being and improve the productivity of basic science researchers during the COVID-19 era. Although it is a small case study with only 19 participants (a limitation), the study provides preliminary evidence that the strategy has a positive impact on participants' well-being and productivity. Moreover, the study design using both cross-sectional and longitudinal studies, provides rigor to our analysis and conclusion. This study does not perform cross-sectional findings for productivity, as comparing data from other basic science research groups may be unfair and difficult. Our study may be utilized, upon optimization, by a specific group to manage the well-being of their research group and maintain productivity during a challenging situation like COVID-19.

IMPLICATIONS AND FUTURE PROSPECTS

From the corporate perspective, all industries have been affected during COVID-19 pandemic, including the energy, tourism, transportation, and retail and manufacturing sectors (Fu and Shen, 2020; Shen et al., 2020). For instance, the performance of companies belonging to energy sectors is found to be negatively impacted in a study performed on the corporate performance in the energy industry by the panel data and Difference-in-Difference model (Fu and Shen, 2020). Therefore, this study could be implemented with or without modifications in every sector to improve the well-being of individuals and enhance their productivity. More specifically, the strategies discussed in this study could be highly beneficial when implemented in healthcare and higher education institutions.

As a vaccine for COVID-19 has not yet been approved, and due to the resurgence of the infection a future limited lock-down may yet take place. Therefore, it is important to continue to optimize the current approach if similar circumstances recur. Due to current fears for a second wave of illness during the flu season, which may further complicate the diagnosis and treatment of COVID-19, it will be beneficial to continue to monitor PSS and COVID-SS regularly. Thus, this finding will provide a potential measure for other research groups to take necessary steps in managing well-being and maintaining productivity in case the second wave leads to either full or partial lock-down and/or lab closures. Furthermore, the second wave of illness will necessitate extra caution in practicing preventive health measures. Research groups, as well as groups in other professions, could use similar empowerment sessions to encourage each other to keep healthy diets, meet exercise goals, and maintain regular sleep schedules, to the extent that their occupations allow.

Finally, the strategy discussed in this study, upon appropriate modification to tailor the situation, could also be implemented in other future challenges that we may face, e.g., new emerging or re-emerging epidemics or pandemics, financial crises, natural disasters, etc. Based on historical perspectives, either locally or globally, we face financial crises and epidemics every decade, as well as natural disasters in multiple countries almost every year (Archer and Geyer, 1982; Roser, 2019; Financial Times, 2020). Therefore, it is important to have a strategy at every institution, especially at research and educational institutions, to effectively mitigate the stress and anxiety caused by these challenges and to improve the well-being and productivity of individuals.

DATA AVAILABILITY STATEMENT

The raw data supporting the conclusions of this article will be made available by the authors, without undue reservation, to any qualified researcher.

ETHICS STATEMENT

The studies involving human participants were reviewed and approved by the Institutional Review Board, University of Tennessee Health Science Center. The

patients/participants provided their written informed consent to participate in this study.

AUTHOR CONTRIBUTIONS

SaK conceived of the presented idea, obtained and analyzed the data, and wrote the first draft of the manuscript. SuK obtained and analyzed the data, and wrote part of the manuscript. AK obtained data, and wrote part of the manuscript. KG obtained data, and wrote part of the manuscript. KZ Obtained additional data and contributed significantly for revision of the manuscript.

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Conflict of Interest: The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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The Discounted Money Value of Human Life Losses Associated With COVID-19 in Mauritius

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Background: Mauritius along with other 12 countries in the African Region was identified at the early start of the COVID-19 pandemic as being at high risk due to high volume of international travel, high prevalence of non-communicable diseases and co-morbidities, high population density and significant share of population over 60 years (16%). The objective of this study was to estimate the total discounted money value of human life losses ($TDMVCL_{MAURITIUS}$) associated with COVID-19 in Mauritius.

Methods: The human capital approach (HCA) was used to estimate the $TDMVCL_{MAURITIUS}$ of the 10 human life losses linked with COVID-19 in Mauritius as of 16 October 2020. The HCA model was estimated with the national life expectancy of 75.51 years and a discount rate of 3%. A sensitivity analysis was performed assuming (a) 5 and 10% discount rates, and (b) the average world life expectancy of 73.2 years, and the world highest life expectancy of 88.17 years.

Results: The money value of human lives lost to COVID-19, at a discounted rate of 3%, had an estimated $TDMVCL_{MAURITIUS}$ of Int$ 3,120,689, and an average of Int$ 312,069 per human life lost. Approximately 74% of the $TDMVCL_{MAURITIUS}$ accrued to persons aged between 20 and 59 years. Reanalysis of the model with 5 and 10% discount rates, holding national life expectancy constant, reduced the $TDMVCL_{MAURITIUS}$ by 19.0 and 45.5%, respectively. Application of the average world life expectancy at 3% discount rate reduced $TDMVCL_{MAURITIUS}$ by 13%; and use of the world highest life expectancy at 3% discount rate increased $TDMVCL_{MAURITIUS}$ by 50%.

Conclusions: The average discounted money value per human life loss associated with COVID-19 is 12-fold the per capita GDP for Mauritius. All measures implemented to prevent widespread community transmission of COVID-19 may have saved the country 837 human lives worth Int$258,080,991. This evidence, conjointly with human rights arguments, calls for increased investments to bridge the existing gaps for achieving universal health coverage by 2030.

Keywords: coronavirus, COVID-19, gross domestic product (GDP), human capital approach (HCA), value of human life

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INTRODUCTION

Mauritius is the second country among the 47 World Health Organization [WHO] African Region [WAFR] member states which graduated to a high-income economy. The Gross National Income (GNI) per capita for 2019 was US$ 12,740, with an estimated population of 1.27 million (1). Furthermore, Mauritius has a human development index of 0.796 and which after adjusting for inequality drops to 0.688. In the same breath, the country has a Gini index of 35.8 (2). As a result of Coronavirus Disease (COVID-19), the economy is expected to experience its first contraction in 40 years. According to the International Monetary Fund (IMF), the real gross domestic product (GDP) growth would contract by 6.8% in 2020 (3).

In 2017, which was before COVID-19 pandemic, Mauritius had a total of 10,332.65 deaths, of which 88.95% were from non-communicable diseases (NCD), 5.28% from injuries, and 5.76% from communicable diseases (CD). The death rates per 100,000 population for various CDs were: 39.12 for chronic respiratory diseases; 25.31 for respiratory infections and tuberculosis; 7.77 for maternal and neonatal disorders; 7.63 for HIV/AIDS and sexually transmitted infections; 2.19 for enteric infections; 1.08 for nutritional deficiencies; 0.14 for neglected tropical diseases and malaria; and 2.66 for other infectious diseases (4).

The COVID-19 outbreak continues to accelerate with a total of 39,175,462 confirmed cases, including 1,102,941 deaths and a case fatality rate of 2.8%, reported globally at 16 October 2020 (5). The African continent had a total of 1,621,853 cases, including 39,150 deaths and a case fatality rate (2.4%). South Africa is the hardest-hit country in the African continent and ranks eleventh globally after the United States of America (USA), India, Brazil, Russia, Spain, Argentina, Colombia, Peru, Mexico and France (5). As of 16 October 2020, there were 415 confirmed COVID-19 cases in Mauritius, including 10 deaths, 364 recovered cases, and 41 active cases (5). The case fatality rate was 2.4% and a recovery rate of 87.7% (5, 6).

Notwithstanding the growing interest for research in the area of COVID-19, there is a dearth of country evidence on the monetary value of human life losses associated with COVID-19. Brazil (7), Canada (8), China (9), France (10), Iran (11), Italy (12), Spain (13), Turkey (14), the United Kingdom [UK] (15), and the USA (16) are exceptions. Quantifying the real disease burden of COVID-19 in dollar terms is critical to building advocacy to increase investment into health-related systems. The objectives of this paper are 2-fold. First, to estimate the discounted money value of human life losses associated with COVID-19 in Mauritius as of 16 October 2020. Secondly, to estimate briefly the potential gains from preventive actions taken to contain the spread of COVID-19.

Mauritius is among the very few countries in the WAFR which has managed to halt the community transmission of COVID-19. There have been no confirmed cases of local transmission since 26 April 2020. The success might be attributed to four systemic reasons.

First, relatively good governance compared to the rest of Africa continent. The Ibrahim Index of African Governance (IIAG) is a tool for tracking African governments progress in attaining the United Nations Sustainable Development (SDG) Goal 16 relating to effective, accountable and inclusive institutions at all levels (17, 18). In 2017, Mauritius had an overall IIAG score of 79.5%, which consisted of category scores of 81.3% in safety and the rule of law (SRL), 77.2% in participation and human rights (PHR), 74.8% of sustainable economic opportunity (SEO), and 84.6% in human development (HD) (19). The Mauritius overall IIAG and the four category scores were higher than Africa's overall IIAG score of 49.9%, and category mean scores of 52.6% in SRL, 49.2% in PHR, 44.8% in SEO, and 52.8% in HD (19).

Second, Mauritius has more resourced national health system and other systems that address social determinants of health than those of many other countries in the WAFR. As shown in **Table 1**, the health workforce, medical devices, infrastructure, essential health service coverage, per capita current health expenditure, and safely managed water and sanitation indicators for Mauritius are significantly higher than those of the WAFR (20–25).

The public and private health sector are manned by a total of 3,210 medical doctors (including 895 specialists), 411 dentists and 4,400 nurses and midwives (27). The doctor population ratio (25.3 per 10,000 population) and nurse and midwifery ratio (35.2 per 10,000 population) in Mauritius are, respectively, 8- and 3-fold higher than those of the WAFR (20, 22).

In 2017, Mauritius per capita current health expenditure (CHE) of US$600 (Int$1,278) was 4.4 times higher than the average of Int$292 in the AFR (25). The percentage of the population with household expenditures on health of more than 25% of the total household income increased slightly from 1.2% in 2012 to 1.8% of the population in 2018 (24, 28). In 2012, 0.34% of households were impoverished by OOP (28). The health system is adequately resourced to keep Mauritius on track to attaining the SDG 3 target 3.8 on achieving universal health coverage (UHC) (18, 29, 30). The Mauritius UHC essential health services coverage index (measured on a scale of 0 to target of 100) of 63% in 2017 was higher than the average of 46% for the WAFR (23).

Third, stronger systems that provide services related to social determinants of health. The proportion of the population using at least basic drinking-water services in Mauritius of 99% was 3-fold that of the WAFR (24, 26). Also, the proportion of the population using improved sanitation services in Mauritius of 91.0% was three-times that of WAFR in 2017 (24, 26).

Fourth, more robust disease surveillance and response system (DSRS) due to better International Health Regulation (IHR) core capacities as recommended by the 58th World Health Assembly (31, 32). In 2013, WHO developed an IHR core capacity monitoring framework consisting of a checklist and indicators that countries can use to monitor progress in the implementation of 13 IHR core capacities (33).

Table 2 shows that, except for the Zoonotic and human-animal interface, all the other 12 IHR core capacity scores for Mauritius were higher than those for the WAFR (34). The average of the 13 IHR core capacities score of 64 was higher than the average for WAFR of 44.

Despite the past relative success, the Ministry of Health and Wellness acknowledges the need to sustain advocacy for

TABLE 1 | Health system and social determinants of health indicators in Mauritius vis-à-vis the WHO African Region (WAFR).

	Value in Mauritius	Average value in WAFR
Health workforce indicators (20)		
Medical doctors per 10,000 population (2018)	25.3	3.0
Nursing and midwifery personnel per 10,000 population (2017)	35.2	10.1
Dentists per 10,000 population (2018)	32.8	–
Pharmacists per 10,000 population (2018)	4.2	–
Medical devices indicators in 2013 (21)		
Computed tomography units per million population	6.4	0.4
Mammography units per million females aged 50–69 years	2.4	7.4
Radiotherapy units per million population	49.7	0.1
Infrastructure indicators in 2013 (22)		
Specialized hospitals per 100,000 population	0.4	–
Provincial hospitals per 100,000 population	0.4	–
District/rural hospitals per 100,000 population	0.16	–
Hospitals per 100,000 population	1.0	0.8
Health centers per 100,000 population	8.84	–
Health posts per 100,000 population	0.16	–
Hospital beds per 10,000 population	34	–
Essential health service coverage indicators in 2017 (23)		
UHC index of service coverage (SCI)	63	46
UHC SCI components: Reproductive, maternal, newborn, and child health	69	54
UHC SCI components: Infectious diseases	53	42
UHC SCI components: Non-communicable diseases	52	71
UHC SCI components: Service capacity and access	80	30
Health financing and catastrophic out-of-pocket health spending (SDG indicator 3.8.2) in 2017		
Population with household expenditures on health >10% of total household expenditure or income (SDG 3.8.2) (%) (24)	8.9	7.26
Population with household expenditures on health >25% of total household expenditure or income (SDG indicator 3.8.2) (%) (24)	1.8	1.78
Current Health Expenditure (CHE) per Capita in PPP (25)	1,278.01	291.9
Domestic General Government Health Expenditure as % of CHE (25)	42.87	55.52
Domestic Private Health Expenditure as % of CHE (25)	56.30	44.48
Out-of-Pocket Expenditure (OOPS) as % of CHE (25)	48.87	35.82
External health expenditure as % of CHE (25)	0.83	21.39
CHE as % Gross Domestic Product (GDP) (25)	5.72	5.65
Domestic general government health expenditure as percentage of GDP (%) (25)	2.45	1.91
Social Determinants of Health in 2017		
Population using safely-managed drinking-water services (%) (24, 26)	>99	29
population using safely-managed sanitation services (%) (24, 26)	96	20

TABLE 2 | Comparison of Mauritius and average WHO African Region IHR score per capacity, 2019.

Core IHR capacities	Mauritius IHR scores	African Region IHR Scores
Legislation and financing	60	43
Coordination and national focal point functions	90	51
Laboratory	53	56
Surveillance	70	61
Human resources	80	49
National health emergency framework	67	40
Health service provision	73	41
Risk communication	80	43
Points of entry	80	36
Chemical events	40	32
Radiation emergencies	40	32
Zoonotic and human-animal interface	20	50
Food safety	80	43
Average of the 13 IHR core capacities	64	44

Source: World Health Organization [WHO] (34).

increased and efficiently utilized investments to bridge the albeit limited persisting gaps in UHC and implementation of some of the IHR core capacities (35). Card and Mooney (36) argue that given the resources available in any health system for saving life are limited, rational allocation of resources is needed, which call for monetary valuation of human life. According to Rice (37), it is important to translate adverse effects of diseases, such as COVID-19, into dollar terms which is the universal language of decision-makers in ministries of economic development, planning, and finance; the private sector; and the international development policy arena.

MATERIALS AND METHODS

Study Area and Overview of Interventions Implemented to Combat COVID-19

The cross-sectional study reported in this paper was undertaken among the ten persons deceased due to COVID-19 in Mauritius between 18 March 2020 (when the first case was discovered) to 16 October 2020.

The Republic of Mauritius implemented a wide array of public health containment measures since the outbreak of COVID-19 was reported in the country on 18 March 2020 to prevent widespread community transmission (6, 38). These included bans on public gatherings, a curfew order, closing of borders, discontinuation of public transportation; closing of schools, universities, shopping malls, and tourist sites; suspending of employee attendance at government and private workplaces (except for essential staff); and introduction of mass testing for antigens on 27 April 2020. As the country recorded no new cases for nearly 3 weeks and no active cases since 11 May 2020, a strategically phased resumption of economic activities began on

15 May 2020. A Work Access Permit issued by the authorities, except for those working in essential sectors became mandatory for employees to resume their duties.

Arrangements were made by the public transport companies to comply with the prescribed health measures and to adhere to the physical distance between passengers. Schoolchildren had to stay at home, while the courses continued to be delivered remotely. Banks and supermarkets still operated on alphabetical order, and the same applied to post offices. Two sets of legislations were enacted mid-May 2020, namely the COVID-19 Bill and Quarantine Bill. Both legislations delineated the transition process from the curfew by strengthening the surveillance control and health system preparedness. These actions ensured a progressive reopening of economic and other activities with strict sanitary rules and added measures to avoid a resurgence of the disease (6, 38).

Notwithstanding the curfew was lifted from end of May 2020, physical distancing guidelines remain in place, as well as the mandatory wearing of masks in public. While working access permits are no longer required, offices are required to incorporate physical distancing requirements, and encourage working from home. All schools reopened in July 2020 while the borders remained closed until the end of September (6, 38).

Empirical Framework

Every human being is imbued with unique capabilities that enable them to enjoy their right to life (Article 3), the right to rest and leisure (Article 24) (39), flourishing as a human (40), and perform expected societal roles (e.g., spouse, carer, breadwinner/worker, taxpayer, commodity consumer, investor, innovator, inventor, mentor, learner, educator, religious worshiper) (41). According to the OECD such capabilities (human capital) include "*The knowledge, skills, competencies and attributes (physical, emotional and mental health plus motivation, and behavior) embodied in individuals that facilitate the creation of personal, social and economic well-being* (p. 18)" (42). The actualization of such capabilities during one's lifetime enables the individual, the family, and the society to flourish or thrive (43). Premature death from COVID-19 (or any other cause) annihilates the stock of those embodied human capital capabilities (including health), capacity to enjoy leisure activities, ability to consume non-health goods and services, capability to contribute to government revenue (via service fees and taxes), ability to save and invest, and ability to produce goods and services for domestic use or export.

The potentially productive years of life lost [YLL] from a COVID-19 death equals the average life expectancy at birth of Mauritius minus the age of onset of death of the specific person. Jones-Lee (44) and Mooney (45) explains and discusses the strengths and limitations of the three approaches used to value monetarily statistical human life, i.e., the human capital approach (HCA), the revealed preferences approach (or implied values), and the willingness-to-pay (or contingent valuation) approach.

The current study employs the HCA originally developed by Petty (46), and after that, refined by Weisbrod (47) and Rice and Cooper (48). According to Weisbrod (47), "*The present value of a man at any given age may be defined operationally as his discounted expected future earnings stream net of his consumption.*" (p. 427). Weisbrod (47), Chisholm et al. (49), and World Health Organization [WHO] (50) recommends use of per capita GDP net of current health expenditure in the valuation of YLL.

Why use net GDP per capita, i.e., the difference between GDP per capita and health care expenditure per capita? Economic theory assumes that every rational individual strives to maximize utility (happiness or pleasure or welfare). The main direct determinants of utility are the consumption of health, non-health goods and services, and leisure (50). Individuals demand health because it is intrinsically pleasurable, allows one to engage in activities of daily living (e.g., schooling, work), and enables one to enjoy leisure activities (e.g., eating and drinking in restaurants, local and international tourism activities, sports, socializing, visiting drama and movie theaters, sports). People demand health goods and services, which do not yield utility, because of the expected positive impact on health, i.e., health-related-quality of life and length of life. Thus, the demand for health goods and services is derived from the demand for health (51). COVID-19 illness (or any other illness) compels individuals (and households) to pay for health goods and services, which reduces household disposable income, and hence, enjoyment of leisure activities and non-health goods and services that directly deliver utility (or pleasure) (49). It is for this reason that WHO (50) recommends:

> "…it is important to note that GDP includes expenditure on health goods and services, so this component should be omitted, and the focus of analysis be redirected toward establishing the present value of discounted aggregate flows of current and future consumption of non-health-related goods and services linked to disease (p.4)".

The current study replicates the HCA model developed by Weisbrod (47), and recently applied in Brazil (7), Canada (8), China (9), France (10), Iran (11), Italy (12), Spain (13), Turkey (14), the UK (15), and the USA (16) to estimate the monetary value of human lives lost due to COVID-19. The total discounted money value of human life losses linked with the 10 COVID-19 deaths in Mauritius ($TDMVCL_{MAURITIUS}$) equals sum of the discounted money value of each case whose outcome was death ($DMVCL_i$). Where 'i' equals Case 1, Case 2, Case 3, Case 4, Case 5, Case 6, Case 7, Case 8, Case 9, and Case 10. Formulaically:

$$TDMVCL_{MAURITIUS} = \sum_{CASE=1}^{CASE=10} DMVCL_i \quad (1)$$

The $DMVCL_i$ for each ith COVID-19 case with death outcome is the sum of the multiplication of discount factor, net per capita GDP for Mauritius, and years of life lost (YLL) per ith case. Where:

a) Discount factor (Q_1) equals $\left[\frac{1}{(1+r)^t}\right]$, r is the discount rate of 3% in this study (7–16, 52), and t is the specific YLL;
b) net per capita GDP equals the difference between GDP per capita (Q_2) minus current health expenditure per person (Q_3) in Mauritius;

c) YLL equals the average life expectancy at birth in Mauritius (Q_4) minus the average age of onset of death for the ith case of COVID-19 (Q_5).

The formula for estimating $DMVCL_i$ for the ith case can be expressed as follows:

$$DMVCL_{i=1,..,10} = \sum_{t=1}^{T} (Q_1) \times (Q_2 - Q_3) \times (Q_4 - Q_5) \quad (2)$$

Where: $\sum_{t=1}^{t=j}$ is the addition from the 1st to year T of life for the ith case, and the meaning of other variables are as defined earlier. 2020 was taken as the base year for the analysis.

Data and Data Sources

The economic model (equations 1 and 2) was estimated using the following data and data sources:

a) Discount rates (Q_1) of 3%, 5%, and 10% from the published past COVID-19 studies (7–16).
b) Data on the GDP per capita (Q_2) of Mauritius of Int$26,460.581 retrieved from the IMF World Economic Outlook Database (53).
c) Data on the current health expenditure per person (Q_3) in Mauritius of Int$1,278.012 from the WHO Global Health Expenditure Database (25).
d) Data on both sexes average life expectancy for Mauritius of 75.51 years (Q_4), the world of 73.2 years, and world highest (Hong Kong Females) of 88.17 years from the Worldometer demographics data (5).
e) Data on the 10 COVID-19 cases that died from the Ministry of Health and Wellness COVID-19 website (6), which is also retrievable from the Worldometer Coronavirus Pandemic Database (5).
f) Data on the ages of onset of death (Q_5) for persons who died of COVID-19 (i.e., Case 1 = 20 years, Case 2 = 42 years, Case 3 = 51 years, Case 4 = 59 years, Case 5 = 59 years, Case 6 = 63 years, Case 7 = 63 years, Case 8 = 69 years, Case 9 = 71 years, Case 10 = 76 years) from the Ministry of Health and Quality of Life COVID-19 database (6).
g) Data on the 155 persons contaminated by 23 positive COVID-19 cases was from the Ministry of Health and Wellness (6).
h) Data on Mauritian 4,500 repatriated from foreign countries, out of them 166 tested positive was from the Ministry of Health and Wellness (6).

Data Analysis

Excel Software (Microsoft, New York) was used to analyse data following the steps below:

Step 1: Equations 1 and 2 in subsection Empirical Framework were built into an Excel spreadsheet.
Step 2: The net per capita GDP for Mauritius was estimated by subtracting current health expenditure per person from per capita GDP for Mauritius, i.e., Int$26,460.581 minus Int$1,278.012 equals Int$25,182.57.
Step 3: The YLL for each of the 10 COVID-19 cases that died was calculated through subtraction of the average age of onset of death from the average life expectancy at birth in Mauritius. The calculation of YLL can be illustrated using Case 1. The average age of onset of death for Case 1 was 20 years, and the average life expectancy for Mauritius was 75.51 years. Thus, the undiscounted YLL for Case 1 equals 55.51, i.e., 75.51 years minus 20 years. The undiscounted YLL for the 10 human lives lost was 187 years (See **Supplementary Table 1**).
Step 4: The discounting of YLL at 3%, 5% and 10% discount rates yielded 124, 100, and 68 years, respectively (See **Supplementary Table 2**).
Step 5: The economic model was estimated using a discount rate of 3%, which is widely applied in health-related studies (25–30, 43, 46). It entailed multiplication of the discounted YLL of 124 years by the net GDP per capita (Int$25,182.57) (See **Supplementary Table 3**).
Step 6: The average money value per COVID-19 death was calculated through the division of the total discounted money value of human lives lost in Mauritius by the total number of deaths, i.e., Int$3,120,689.13 divided by 10 deaths.
Step 7: The average money value per person in population was estimated through the division of the total discounted money value of human lives lost by the total population in 2020 for Mauritius, i.e., Int$3,120,689.13 divided by 1,271,766.
Step 8: Two univariate sensitivity analyses were conducted to test the impact of uncertainty surrounding two variables. First, due to the lack of consensus in the health economics literature, uncertainty surrounds the choice of discount rate (54, 55). In order to test the impact of changes in the discount rate on the $TDMVCL_{MAURITIUS}$, the model was recalculated using discount rates of 5% and 10% (7–16, 56, 57). Second, there is no consensus regarding whether to apply the national average life expectancy at birth or the world highest average life expectancy at birth in the calculations of YLL (7–16). The economic model was first estimated using the national average life expectancy at birth for Mauritius, and subsequently, reanalysed with the global average life expectancy at birth and the world highest average life expectancy at birth (i.e., female average life expectancy in Hong Kong).
Step 9: The potential gains due to COVID-19 contact tracing and quarantine were estimated. The step entailed calculation of the:

a) Case fatality rate = actual 10 COVID-19 deaths divided by total COVID-19 cases of 344 (1) = 10/344 = 0.0290697674418605.
b) Contaminations per patient = 155 persons contaminated divided by 23 contaminators (5) = 155/23 = 6.73913043478261.
c) Number protected by quarantine = 166 quarantined cases times contamination per patient (6.73913043478261) = 1,119.
d) Number of COVID-19 deaths averted = 1,119 protected cases times case fatality rate (0.0290697674418605) = 33.
e) The discounted money value of human lives saved with quarantine was equal the 33 deaths averted times the average discounted monetary value per human life of Int$312,069.

TABLE 3 | The total discounted money value of human lives lost due to COVID-19 in Mauritius: assuming national life expectancy of 75.51 years and a discount rate of 3%.

Case number and age at onset of death	Discounted money value per human life lost (Int$)	Percent
Case 1: 20 years	679,060	21.8
Case 2: 42 years	532,154	17.0
Case 3: 51 years	438,508	14.1
Case 4: 59 years	331,557	10.6
Case 5: 59 years	331,557	10.6
Case 6: 63 years	267,815	8.6
Case 7: 63 years	267,815	8.6
Case 8: 69 years	156,894	5.0
Case 9: 71 years	115,329	3.7
Case 10: 76 years	0	0
Total	3,120,689	100.0
Average	312,069	

TABLE 4 | The total discounted money value of human lives lost due to COVID-19 in Mauritius: assuming 5 and 10% discount rates (in 2020 Int$).

Case number and age at onset of death	Discounted money value per human life lost at 5% discount rate (Int$)	Discounted money value per human life lost at 10% discount rate (Int$)
Case 1: 20 years	470,877	250,615
Case 2: 42 years	407,779	241,969
Case 3: 51 years	354,922	228,583
Case 4: 59 years	283,910	202,003
Case 5: 59 years	283,910	202,003
Case 6: 63 years	236,554	178,881
Case 7: 63 years	236,554	178,881
Case 8: 69 years	145,716	122,599
Case 9: 71 years	109,027	95,462
Case 10: 76 years	0	0
Total	2,529,250	1,700,996
Average	252,925	170,100

Step 10. The potential gains from all measures (which are stated in the Methods section) taken by the Government and people of Mauritius to prevent widespread community transmission of COVID-19 were estimated by multiplying the 837 predicted number of deaths from Cabore et al. (58) by average discounted money value per human life.

Ethics Approval

Ethics approval was not necessary since the study did not involve human or animal subjects. It relied exclusively on the analysis of secondary data from IMF (53), Mauritius Ministry of Health and Wellness (6), WHO (24, 25), and Worldometer (5) databases. The data is freely accessible to the public.

RESULTS

Findings of Analysis With Mauritius Life Expectancy of 75.51 Years and a 3% Discount Rate

As depicted in **Table 3**, the 10 human lives lost to COVID-19 had an estimated total discounted money value of Int$3,120,689, and an average of Int$312,069 per human life lost.

Of the total discounted money value of human lives lost due to COVID-19 (TDMVCL), 21.8% accrued to the 20 year-old case, 17.0% to the 42 year-old case, 14.1% to the 51 year-old case, 21.2% to the two 59 year-old cases, 17.2% to the two 63 year-old cases, 5.0% to the 69 year-old case, 3.7% to the 71 year-old case, and 0.0% to the 76 year-old case. The discounted money value per human life diminishes with increase in age. For instance, the discounted money value of the 20 year-old case was 6-fold higher than that of the 71 year-old case. Approximately 74.1% of the TDMVCL accrued to persons aged between 20 and 59 years, i.e., the most product age bracket.

Findings of Reanalysis With 5 and 10% Discount Rates With Mauritius Life Expectancy of 75.51 Years

Table 4 presents the results of sensitivity analysis of using 5 and 10% discount rates.

Reanalysis of the model with a discount rate of 5%, while holding national life expectancy constant, reduced the TDMVCL by Int$591,439 (19.0%), and the value per human life by Int$59,144. Re-estimation of the model with a 10% discount rate, holding the national life expectancy constant, decreased the TDMVCL by Int$1,419,693 (45.5%), and the value per human life by Int$141,969.

Findings of Reanalysis With the Average Global Life Expectancy of 73.2 Years and the World Highest Life Expectancy of 88.09 Years Holding Discount Rate Constant at 3%

Table 5 portrays findings of recalculation of the economic model substituting the national life expectancy with the average world life expectancy and the world highest life expectancy.

Application of the average world life expectancy of 73.2 years, with a 3% discount rate, slashed the TDMVCL by Int$411,159 (13%), and the value per human life by Int$41,116. Recalculation of the model with the highest life expectancy in the world of 88.09 years, holding discount rate constant at 3%, enlarged the TDMVCL by Int$1,574,773 (50%), and the average discounted money value per human life by Int$157,477.

Potential Gains From COVID-19 Contact Tracing and Quarantine

Without contact tracing and quarantine, a total of 43 persons would have died due to COVID-19 with a monetary value of

TABLE 5 | The total discounted money value of human lives lost due to COVID-19 in Mauritius—assuming average global and world's highest life expectancies (in 2020 Int$).

Case number and age at onset of death	Discounted money value per human life lost at average global life expectancy of 73.2 years and 3% discount rate (Int$)	Discounted money value per human life lost at average world highest life expectancy of 88.09 years and 3% discount rate (Int$)
Case 1: 20 years	664,190.0	726,946
Case 2: 42 years	503,662.2	623,909
Case 3: 51 years	401,332.5	558,228
Case 4: 59 years	284,464.2	483,215
Case 5: 59 years	284,464.2	483,215
Case 6: 63 years	214,812.4	438,508
Case 7: 63 years	214,812.4	438,508
Case 8: 69 years	93,606.1	360,710
Case 9: 71 years	48,186.1	331,557
Case 10: 76 years	0	250,667
Total	2,709,530	4,695,463
Average	270,953	469,546

Int$13,269,240, i.e., Int$10,148,550 (value of 33 averted deaths) plus Int$3,120,689 (value of 10 actual dead cases). Therefore, quarantine helped Mauritius to save 33 human lives with a discounted monetary value of Int$10,148,550, i.e., the 33 deaths averted times average discounted monetary value of Int$312,069 per human life.

Potential Gains From All Measures Taken by the Republic of Mauritius to Prevent Widespread Community Transmission of COVID-19

The widespread community transmission of COVID-19 infection in Mauritius, as predicted by Cabore et al. (58) would have led to a total of 837 losses in human lives with a total discounted monetary value of Int$261,201,681, i.e., 837 deaths times average discounted money value of Int$312,069 per human life. Thus, all measures implemented in the Republic of Mauritius to prevent widespread community transmission of COVID-19 may have saved the country a total of Int$258,080,991, i.e., Int$261,201,681 minus Int$3,120,689 (total value of the actual 10 deaths).

DISCUSSION

Key Findings and Implications

- The 10 human lives lost to COVID-19 had an estimated total discounted money value of Int$3,120,689.
- The average discounted money value per human life was Int$312,069.
- Reanalysis of the model with discount rates of 5 and 10% attenuated the TDMVCL by 19.0 and 45.5%, respectively.
- The application of the average global life expectancy of 73.2 years slashed the TDMVCL by 13%.
- The use of highest life expectancy in the world of 88.09 years enlarged the TDMVCL by 50%.
- Quarantine saved 33 human lives with a discounted monetary value of Int$10,148,550.

All measures implemented to prevent widespread community transmission of COVID-19 may have saved the country 837 human lives worth Int$258,080,991. The economic impacts of COVID-19, as well as the implementation of related containment public health measures, are well-determined. In April 2020 the IMF forecasted that the national economy would contract by 6.8% in 2020. As long as other countries are not COVID-19 free, Mauritius, which is an economy heavily dependent on the tourism industry remains vulnerable to the Specter of the global pandemic. In the same vein, the national debate whether to open the borders to give some breathing space and to allow the tourism industry to remain afloat financially is high on the agenda. However, as the threat of the pandemic still looms, the economic loss due to public health measures should be weighed against the potential gains estimated at Int$261,201,681. While containment measures come at a cost and stop in economic activity, beyond economics, the priority should be on the impact on length and quality of life of people.

The TDMVCL was 0.009% of the total GDP (in PPP) for Mauritius in 2020. Whereas, the average discounted money value per human life loss associated with COVID-19 was 12-fold the per capita GDP for Mauritius.

An increase in the discount rate from 3 to 10% results in a drop in TDMVCL from Int$3,120,689 to Int$1,700,996. This represents a 46% decrease. Also, a 16.7% growth in the average life expectancy at birth leads to an expansion in TDMVCL of 50%. This result confirms the findings from past studies that indeed, the magnitude money value of human life losses is dependent on both the discount rate and the average life expectancies used (7–16).

Comparison With Other Studies

Table 6 provides a comparison of the findings from the Mauritius study with those of 10 other countries that employed the HCA to estimate the monetary value of human life losses associated with COVID-19.

The total discounted money value of human life losses in Mauritius was 1,151-fold lower than those of Brazil (7); 653-fold of Canada (8); 296-fold of China (9); 3,362-fold of France (10); 1,125-fold of Iran (11); 4,188-fold of Italy (12); 3,086-fold of Spain (13); 352-fold of Turkey (14); 3,167-fold of the UK (15); and 6,338-fold of the USA (16). The differences could be attributed to significantly lower number of COVID-19 deaths in Mauritius compared to the six other countries.

The average discounted money value per human life in Mauritius was higher than the other six countries (Brazil, Canada, Iran, Turkey, UK, and USA), which is related to higher mortality rate in the younger age groups in Mauritius. As the share of deaths in Canada, France, Italy, Turkey, UK and USA in the older age group of 60 years and above was considerably much higher,

TABLE 6 | A comparison of Mauritius discounted money value of human life losses associated with COVID-19 to those of 10 other countries.

Countries	Total discounted money value of human life losses	The average discounted money value per human life
Mauritius*	Int$3,120,689	Int$312,069
Brazil (7)	Int$3,591,028,164	Int$99,629
Canada (8)	Int$2,037,021,173	Int$231,217
China (9)	Int$924,346,795	Int$356,203
France (10)	Int$10,492,290,194	Int$339,381
Iran (11)	Int$3,510,063,043	Int$165,187
Italy (12)	Int$13,070,141,190	nt$369,088
Spain (13)	Int$9,629,234,112	Int$470,798
Turkey (14)	Int$1,098,469,122	Int$228,514
United Kingdom [UK] (15)	Int$9,883,426,226	Int$225,104
United States of America [USA] (16)	Int$19,780,290,991	Int$292,889

*Sources: *Estimates from the current study. Sources for other countries are referenced in the Table.*

the component of years' life lost (life expectancy less age at onset of death due to COVID-19) is lower. Conversely, as people died from COVID-19 at relatively younger age in China and Spain, the benefits/returns foregone had these people stayed alive are much higher per person in China and Spain compared to Mauritius.

Strengths of the Study

This study applied HCA, a well-known economic methodology, to monetarily value the human life losses associated with COVID-19 in Mauritius. It is the first study of its kind in Mauritius. The evidence presented in this paper can be judiciously used by the Ministry of Health and Wellness to make a case for augmenting investments to strengthen health-related systems to bridge extant service coverage gaps. Universal coverage of health and health-related services would contribute in assuring every citizen's right to life, and achievement of the SDG3 on "Ensuring healthy lives and promote well-being for all at all ages" and SDG6 on "Ensuring availability and sustainable management of water and sanitation for all" [(18), p. 14].

Limitations of the Study

The study had some shortcomings. First, the scope of the study was limited to the impact of COVID-19 on the life expectancy of the ten persons who died. Therefore, since the study did not evaluate both the costs and consequences of alternative COVID-19 control intervention options, the study findings can only be used for advocacy and not to inform policy development and decision-making.

Second, the study did not include the cost of societal resources expended in prevention (water, sanitation, handwashing with soap, hand-sanitisers, facial masks, personal protective equipment for health workers), quarantine, testing, contact-tracing, treatment, and rehabilitation of the 332 cases that recovered from COVID-19 infection. It did not also include the cost of diagnosis, treatment, post-mortem, mortuary storage, and interment of the 10 cases that died.

Third, Santarpia et al. (59) conducted a study among 13 individuals with COVID-19 isolated at the University of Nebraska Medical Center to examine aerosol and surface contamination with SARS-CoV-2. The authors found that "*…data indicate significant environmental contamination in rooms where patients infected with SARS-CoV-2 are housed and cared for, regardless of the degree of symptoms or acuity of illness. Contamination exists in all types of samples: high and low-volume air samples, as well as surface samples including personal items, room surfaces, and toilets*" (p.3). This implies that since there may still be aerosol and surface contamination at quarantine and isolation centers, we may have overestimated the effect of quarantine, and hence, the potential discounted money value of human lives saved.

Fourth, the HCA approach used has a number of weaknesses: (a) it uses GDP per capita to value the YLL, which ignores non-market contributions to societal welfare, the negative impact of economic production processes (e.g., on climate change), inequalities in the distribution of wealth and income, and quality of life (60); (b) values the YLL above the national average life expectancy at birth at zero; (c) assumes that the only objective of improving (or sustaining) human health (health-related quality and length of life) is to contribute to economic production (61), which disregards other objectives such as assuring human rights (39), and enabling homo sapiens to flourish (40).

CONCLUSION

This study succeeded in estimating the discounted money value of human life losses associated with COVID-19 in Mauritius as of 16 October 2020. The average discounted money value per human life loss associated with COVID-19 of Int$312,069 is significant, since it is 12-fold the per capita GDP for Mauritius. As noted earlier, the Republic of Mauritius prompt action in arresting the spread of COVID-19 infections, optimizing recoveries, and limiting the number of deaths is laudable. All measures implemented to prevent widespread community transmission of COVID-19 may have saved the country 837 human lives worth Int$258,080,991. This effectiveness has been attributed to relatively good political governance, and a highly performing national health system, disease surveillance and response system, and other systems that address social determinants of health.

The Ministry of Health and Wellness can use the evidence contained in this paper, conjointly with human rights (to life, health, and health care) arguments, to sustain advocacy for further increase in multisector investments to bridge the existing limited gaps in UHC, IHR core capacities, and social determinants of health to mitigate and to respond to future public health emergencies, and to sustain the good health indicators.

In order to guide decision-making related to COVID-19, there is a need for studies that estimate both costs and consequences of alternative prevention (e.g., lockdown,

handwashing, physical distancing), contact-tracing, quarantine, treatment, and rehabilitation interventions (62, 63).

DATA AVAILABILITY STATEMENT

The original contributions presented in the study are included in the article/**Supplementary Materials**, further inquiries can be directed to the corresponding author/s.

AUTHOR CONTRIBUTIONS

LM, AN, and JK designed the study, extracted the data on per capita GDP from IMF database, current health expenditure per person from WHO Global Health Expenditure database, number of COVID-19 deaths in Mauritius from the Worldometer database, ages of onset of death from the Republic of Mauritius Ministry of Health and Wellness website, developed the human capital approach model on Excel software, and wrote the manuscript. All authors have read and agreed to the published version of the manuscript.

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SUPPLEMENTARY MATERIAL

The Supplementary Material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/fpubh.2020.604394/full#supplementary-material

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The remaining author declares that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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Predicting Hospital Demand During the COVID-19 Outbreak in Bogotá, Colombia

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Colombia, like many developing nations, does not have a strong health system able to respond to a pandemic of the magnitude of Covid-19. There is an increasing need to create a model that allows particular clinics and hospitals to estimate the number of patients that require Intensive Care Units-ICU care (critical), and the number of patients that require hospital care (severe), but not ICU care, in order to manage their limited resources. This paper presents a prediction of the total number of ICU and regular beds that will be needed in Bogotá, Colombia, during the COVID-19 pandemic. We use an SEIR model that includes three different categories of infection: those who can stay at home, those who need regular hospital beds, and those who need ICU treatment. The model allows for a time varying transmission rate which we use to incorporate the measures introduced by the government over the period of one semester. The model predicts that by mid November 2020, the city will need 1362 ICU beds and more than 9000 regular hospital beds. The number of active cases will be 67,866 by then and the death toll will reach 13,268 people by the end of December. We provide a Shiny app available at https://claudia-rivera-rodriguez.shinyapps.io/shinyappcovidclinic/. The original values in the app reproduce the results of this paper, but the parameters and starting values can be changed according to the user's needs. COVID-19 has posed too many challenges to health systems around the globe. This model is a useful tool for cities, hospitals and clinics in Colombia that need to be prepared for the excess demand of services that a pandemic like this one generates. Unfortunately, the model predicts that by mid-November the projected capacity of the system in Bogotá will not be enough. We expect the lockdown rules to be strengthened in future days, so the death toll will not be as bad as predicted by this model.

Keywords: COVID-19, SEIR, Bogotá, compartmental model, Colombia

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1. BACKGROUND

The novel coronavirus disease 2019 (COVID-19) epidemic had spread from China to almost all the countries in the world by April 1, 2020. The first official case was reported in Colombia on March 6, 2020, from an imported case, and evolved to local cases of transmission. In order to reduce the impact of the COVID-19 outbreak in Bogotá, the largest city in Colombia, a local lockdown was introduced on March 15, 2020, followed by a national lockdown on March 19, 2020. Colombia,

like many developing nations, does not have a strong health system able to respond to a pandemic of the magnitude of the present one. Neither in terms of infrastructure and medical personnel, nor in terms of logistical preparedness and the technical capacity to provide all medically needed resources. The latter is the main motivation to create a model that allows particular clinics and hospitals to estimate the number of beds and respirators needed during the peak days. Specifically, we are interested in estimating the number of patients that require Intensive Care Units-ICU care (critical), and the number of patients that require hospital care (severe), but not ICU care.

As of April 4, 2020, Colombia had only carried out 460 tests per million people (https://infogram.com/, https://ourworldindata.org/covid-testing), whereas other countries, such as Germany and South Korea, had carried out over 1,000 tests per million people. Additionally, on March 26, one of the two available machines used to run the detection tests broke, leading to a reduction operations and causing delays in the detection of the total number of cases. Unfortunately, for developing countries like Colombia, it has been an enormous effort to expand facilities and the production of biotechnology inputs to run the necessary number of tests required to detect all active cases of the virus; the highest number up to date has been 17,000 tests, on June 19, 2020. Thus, one of the biggest concerns is that the data may not be well-informative as to how many hospital beds (and ICU beds) will be needed during the peak of the outbreak. In fact, one of the main caveats for this study is that the official data is very likely to be under estimated, as only patients with at least one symptom or that have had contact with another detected case are being tested (1) (National Health Institute by its acronym in Spanish). Moreover, we are employing an overall probability of requiring ICU treatment, although sex, age, and co-morbidity (diabetes, hypertension, acute respiratory diseases, and depressed immune system) give rise to differential probabilities, that are not taken into account here.

We implemented an SEIR model (Susceptible - Exposed - Infectious - Recovered) to forecast the number of cases in Bogotá, the largest city in Colombia and the one with the largest numbers of cases to date, using the public official COVID-19 information from the Health Secretariat-Saludata and available at (http://saludata.saludcapital.gov.co/osb). The model includes three different categories of infection: Infected that require ICU care, Infected that require hospital care, but not ICU care, and Infected that only require Home care. The model accounts for the effect of control strategies introduced by the government by changing the transmission rate over time. We developed a Shiny app that displays the results from the model. It is publicly available at (https://claudia-rivera-rodriguez.shinyapps.io/shinyappcovidclinic/). Users can change the initial parameters according to their specific situation. The Shiny app can work as a forecasting tool for individual clinics by specifying the market share (percentage) of the population corresponding to the clinic. During the outbreak, some clinics should be ready to see an increase in their market share because they may have more resources, such as ICU beds, and the model allows each clinic to adjust this. The model can be used for specific cities or towns: the user only needs to change the population size and some of the parameters of interest.

Abbreviations: SEIR, Susceptible-Exposed-Infected-Recovered; ICU, Intensive Care Unit; COVID-19, Coronavirus disease 2019.

2. METHODS

SIR methods (Susceptible-Infected-Recovered) have become widespread in the prediction of communicable diseases since their creation in the early 20th century (2). Several authors have provided forecasting models using this method, as presented in (3), but SIR models rely heavily on initial assumptions that are strong. SEIR models are a variation that relaxes some of those assumptions, including closed populations, and account for communicable diseases that transmit in transitions, starting from the entire population (Susceptible) that incubate the disease for a period of time (Exposed) making the person infected but not infectious (I) and finally become Recovered (R) (4). Each transition has a rate based on what is observed from a population, that is, a susceptible person gets infected at a transmission rate once in contact with an infected individual, and becomes exposed. Once exposed, the transition to infected happens at a rate that captures the inverse of the mean latent period of the disease. The final transition is recovery with permanent immunity. We chose this model to estimate the demand for beds for each institution in Colombia, distinguishing between regular and ICU (Intensive Care Units) beds, which allows different transition rates for each type. We also estimate the requisite preparedness and logistical needs for the health providers. Similar methods have been used to forecast similar needs in Europe and the United States of America (5–7) and more recently they have also been part of the discussion in developing nations: SIR models are also used to forecast the virus progression in Colombia.

3. MODEL

We fitted a deterministic SEIR model over 6 months. For practical purposes, it is important to bear in mind that policies were changing over this period of time, and therefore models must be updated. The population is divided into compartments or states that individuals transition from one state to the other, corresponding to Susceptible (S), Exposed (E), Infected (I), recovered (R), and death (D). Those Infected (I) are subdivided into three compartments: $I_{\mathrm{U}}, I_{\mathrm{NoU}}, I_{\mathrm{H}}$ which, respectively, denote infected individuals that require ICU care, infected individuals that require hospital care but not ICU, and infected individuals that only require home care.

One implication of our model is that it does not consider events such as births or migration, and it only considers deaths due to COVID-19. Note that we assume that patients transit from E to ICU care directly, therefore we assume that the average time from (E) to (I_{U}) is larger than the average time from (E) to (I_{NoU}) and subsequently this is larger than the average time from (E) to (I_{H}). These transitions and considerations are summarized in **Figure 1**. We also assume that the only patients

that transition to death are those in ICU, whilst other infected patients recover: this assumption is based on the fact that at the beginning of the pandemic, when this document was written, there was no collected evidence besides patients in clinics, and the observed rates showed a disproportionately large mortality rate for ICU patients in Wuhan and Washington State (8, 9). The total population of Bogotá is 7.4 million, but we assume an initial population size of 8 million to account for its metropolitan area because people commute daily to work and study from the surrounding towns to Bogotá's Capital District.

We describe the epidemic transitions through the model using the following equations.

$$\frac{dS(t)}{dt} = -\beta(t)S(t)\frac{(I_{\mathrm{U}}(t) + I_{\mathrm{NoU}}(t) + I_{\mathrm{H}})(t)}{N} \quad (1)$$

$$\frac{dE(t)}{dt} = \beta(t)S\frac{(I_{\mathrm{U}}(t) + I_{\mathrm{NoU}}(t) + I_{\mathrm{H}}(t))}{N} - (\kappa_{\mathrm{U}} + \kappa_{\mathrm{NoU}} + \kappa_{\mathrm{H}})E(t) \quad (2)$$

$$\frac{dI_{\mathrm{U}}(t)}{dt} = \kappa_{\mathrm{U}}E(t) - \gamma_{\mathrm{U}}I_{\mathrm{U}}(t) \quad (3)$$

$$\frac{dI_{\mathrm{NoU}}(t)}{dt} = \kappa_{\mathrm{NoU}}E(t) - \gamma_{\mathrm{NoU}}I_{\mathrm{NoU}}(t) \quad (4)$$

$$\frac{dI_{\mathrm{H}}(t)}{dt} = \kappa_{\mathrm{H}}E(t) - \gamma_{\mathrm{H}}I_{\mathrm{H}}(t) \quad (5)$$

$$\frac{dR(t)}{dt} = (1-d)\gamma_{\mathrm{U}}I_{\mathrm{U}}(t) + \gamma_{\mathrm{NoU}}I_{\mathrm{NoU}}(t) + \gamma_{\mathrm{H}}I_{\mathrm{H}}(t) \quad (6)$$

$$\frac{dD(t)}{dt} = d\gamma_{\mathrm{U}}I_{\mathrm{U}}(t) + \gamma_{\mathrm{NoU}}I_{\mathrm{NoU}}(t) + \gamma_{\mathrm{H}}I_{\mathrm{H}}(t) \quad (7)$$

$$N = S(t) + I(t) + R(t) + D(t) \quad (8)$$

where $\kappa_{\mathrm{NoU}} = p_{\mathrm{NoU}}\kappa$, $\kappa_{\mathrm{U}} = p_{\mathrm{U}}\kappa$ and $\kappa_{\mathrm{H}} = p_{\mathrm{H}}\kappa$. This set of equations is the core model, where, at time t, the population is divided into susceptible ($S(t)$), exposed ($E(t)$), infected ICU ($I_{\mathrm{U}}(t)$), infected in hospital but not ICU ($I_{\mathrm{NoU}}(t)$), infected that require only home care ($I_{\mathrm{H}}(t)$), recovered ($R(t)$) and dead subjects ($D(t)$) individuals. The total of infected individual is $I(t) = I_{\mathrm{U}}(t) + I_{\mathrm{NoU}}(t) + I_{\mathrm{H}}(t)$, with respective proportions $p_{\mathrm{U}}, p_{\mathrm{NoU}}$, and p_{H}. The transmission rate, $\beta(t)$, controls the rate of spread, i.e., the probability of transmitting disease between a susceptible and an infectious individual. We allow this to be a step-wise function to adjust for the measures taken by local authorities to control the spread of the virus. The term $1/\kappa$ represents the mean incubation period and $\gamma_{\mathrm{U}}, \gamma_{\mathrm{NoU}}$, γ_{H} are the daily probabilities that the respective patients recover. Furthermore, d denotes the probability of death for ICU patients. The model's transitions are described in **Figure 1**. Equation (1) describes the rate at which new individuals are exposed, this rate is $\beta(t)S(t)\frac{I(t)}{N}$; Equation (2) describes the rate at which exposed individuals become infected, this rate is $(\kappa_{\mathrm{U}} + \kappa_{\mathrm{NoU}} + \kappa_{\mathrm{H}})E(t)$. Infected individuals become infected in one of the three categories: $I_{\mathrm{U}}(t) + I_{\mathrm{NoU}}(t)$, and $I_{\mathrm{H}}(t)$ with probabilities $p_{\mathrm{U}}, p_{\mathrm{NoU}}$, and p_{H}, respectively. Additionally, Equation (3) describes the rate at which infected individuals in *ICU* either die or recover, this rate is $\gamma_{\mathrm{U}}I_{\mathrm{U}}(t)$. Similarly, Equation (4) represents the rate at which infected individuals in hospital (but, not *ICU*) either dies or recover, this rate is $\gamma_{\mathrm{NoU}}I_{\mathrm{NoU}}(t)$ and Equation (5) describes the rate at which infected individuals at home either die or recover: $\gamma_{\mathrm{H}}I_{\mathrm{H}}(t)$. Equation (6) describes the rate at which infected individuals recover. Note that this rate is always positive and the number of recovered individuals never decreases. Similarly, Equation (7) describes the rate at which infected individuals die. Note that only individuals from *ICU* die and this rate is also positive. The total population is $N = S(t) + I(t) + R(t) + D(t)$ (Equation 8).

We are aware that other variables, beyond total population counts, such as age and sex distribution and having an identified co-morbidity such as obesity, diabetes, hypertension, and/or cancer, increases the probability of developing complications due to Covid-19 that increase the chances of dying. However, Colombian data was not available at the microdata level when the pandemic erupted, and still is not available, not even in tabular form, including any of these additional variables. Hence, the best we could do was to implement the model for the general observed numbers.

To model the impact of the interventions introduced by the government, we allow the transmission rate to be a step-wise function $\beta(t)$, with three steps at t_0, t_1 and t_2. The time t_0 (2020-05-24) corresponds to the time when we start predicting, t_1 (2020-06-16) is when new measures were introduced, and t_2 (2020-06-30) is the date when measures were revised and implemented. We estimate $\beta(t_0)$ from the basic reproduction number such that $R_0 = 1.1$ (10). For $t > t_0$, we choose $\beta(t)$ such that $R(t) \approx 1.3$, for $t_1 \leq t < t_2$ and $R(t) \approx 1.2$, for $t \geq t_2$ (10) (**Appendix**).

The terms p_{U}, p_{NoU} and p_{H} denote the probabilities that a case requires ICU care, hospital non-ICU care, and only home care, respectively. Note that $p_{\mathrm{U}} + p_{\mathrm{NoU}} + p_{\mathrm{H}} = 1$. To estimate these probabilities, we use information from the Colombian National Health Institute, finding $p_{\mathrm{U}} = 0.0168$, $p_{\mathrm{NoU}} = 0.14$ and $p_{\mathrm{H}} = 0.843$. The parameter κ is the daily probability of an exposed individual becoming infected, and $\gamma_{\mathrm{U}}, \gamma_{\mathrm{NoU}}, \gamma_{\mathrm{H}}$ are the daily probabilities that an infected individual recovers given that they are in ICU, Regular bed and home, respectively. The probability d denotes the probability that an infected ICU individual dies. **Table 1** displays the parameters of the models, their interpretation and sources. The starting values for the model are based on the numbers from Bogotá, Colombia reported by May 24. There where 7,166 cases, 1,318 recovered, and 212 deaths by then in the city.

4. RESULTS

Figure 2 shows the results the model predicts for each category. Even with all the positive measures assumed in the model, we predict that the peak of the epidemic could happen around November 11, 2020. During the peak of the epidemic, the model predicts that 1,362 ICUs will be needed for coronavirus patients, and 9,470 non-ICU hospital beds. We predict that the maximum number of prevalent cases will be 67,866 (2020-11-14) for the 6 months of the prediction. With the parameters in the models, the total number of deaths could reach 13,268 in 6 months' time.

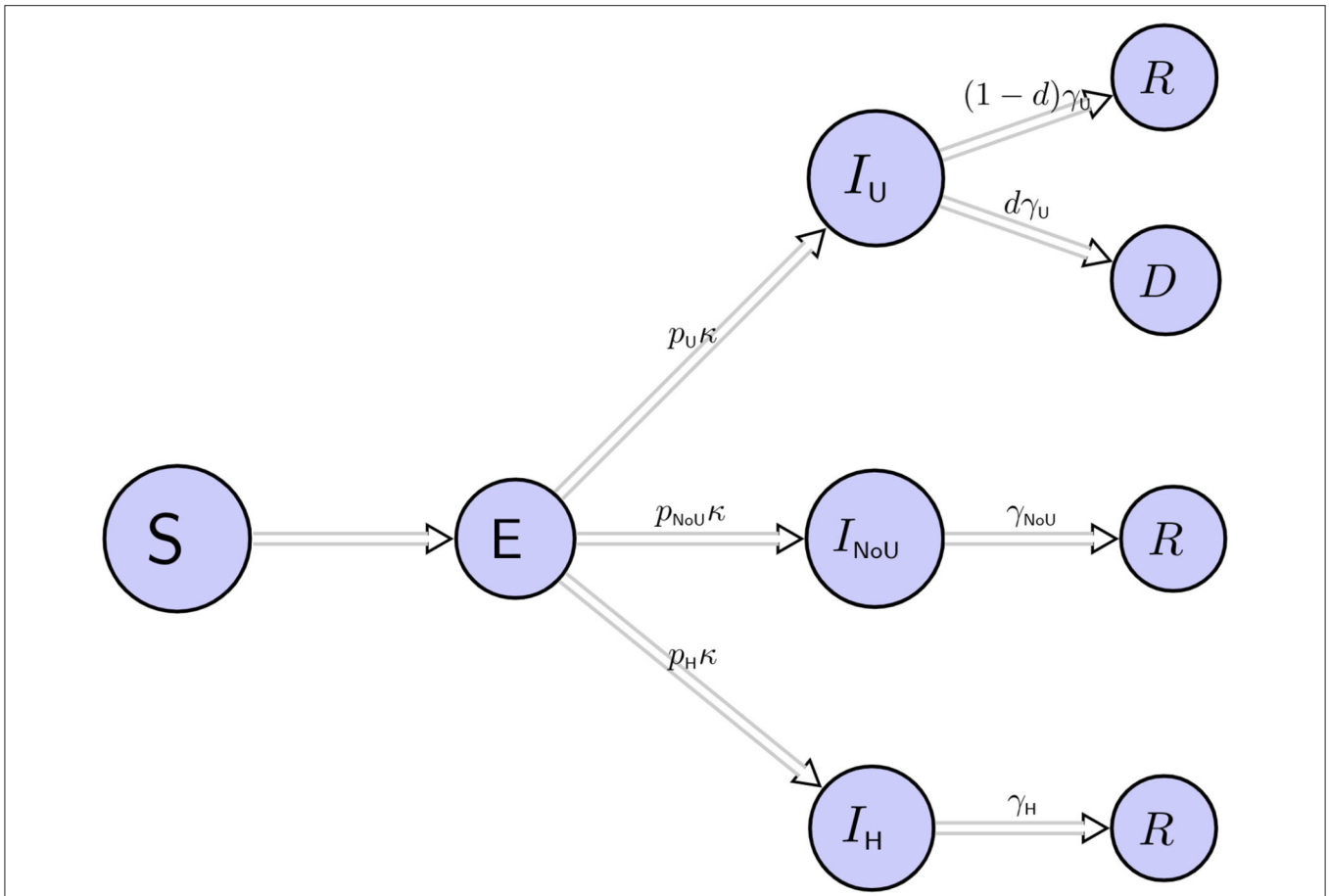

FIGURE 1 | We divided the population into susceptible (S), exposed (E), infected ICU (I_U), infected in hospital but not ICU (I_{NoU}), infected that require only home care (I_H), recovered (R), and dead subjects (D). Infected subjects are I_U, I_{NoU} or I_H with probabilities p_U, p_{NoU} and p_H, respectively. The term $1/\kappa$ is the mean incubation period and $\gamma_U, \gamma_{NoU}, \gamma_H$ are the daily probabilities that the respective patients recover. d is the probability of death for ICU patients.

TABLE 1 | Parameters and definition of model (1).

Symbol	Definition	Value	Source
$\beta(t)$	Transmission rate	Stepwise function	(11, 12)
κ	Daily probability of an exposed individual becoming infected: $\kappa = 1/\alpha$, with α being the mean incubation period	1/5.2	(13)
p_U	Probability of patient being ICU	0.0168	(10)
p_{NoU}	Probability of patient being in Hospital, but not ICU	0.14	(10)
p_H	Probability of patient being mild/at home	0.843	(10)
γ_U	Daily probability that an infected individual in ICU recovers, when the mean infection period is b_U, $\gamma_U = 1/b_U$	1/6	(13–15)
γ_{NoU}	Daily probability that an infected individual in Hospital, but not ICU, recovers, when the mean infection period is b_{NoU}, $\gamma_{NoU} = 1/b_{NoU}$	1/5	(13–16)
γ_H	Daily probability that an infected individual in Hospital, but not ICU, recovers, when the mean infection period is b_H, $\gamma_H = 1/b_H$	1/5	(13–16)
d	Probability of dying given that patient is in ICU	0.50	(17)

Figure 3 displays a closer picture of those infected and the total number of deaths. We can see that the total number of infected that will need hospital care (ICU and non-ICU) is high enough for concern. Additionally, **Figure 4** shows those infected that will need hospital care, compared to the current number of ICU beds in the city. It shows that the number of ICUs needed will be 1,362, i.e., the city has to increase its capacity in order to provide care to everyone that needs it. The local authorities in

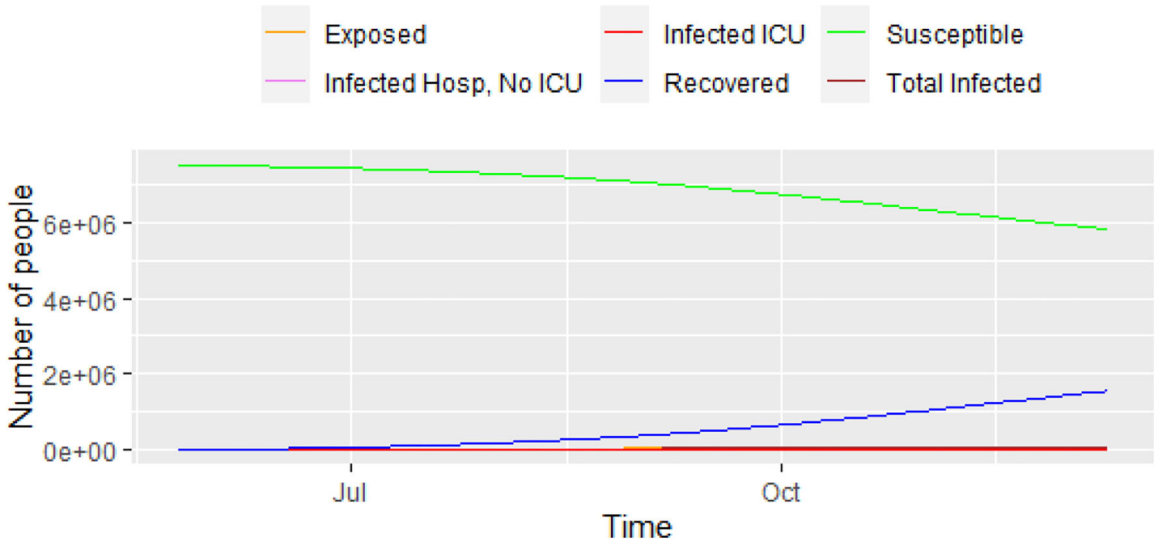

FIGURE 2 | Progress of the epidemic using model (1).

Bogotá are planning to have a total of 1,200 ICU beds in the city, but the current number is still lower than that. The number 1,200 will be overrun by mid-September, 2020, with a death toll of 4,850 people by then. Unfortunately, the trend keeps on increasing over the following months, which reflects the lack of preparedness for a catastrophe like the current one in Bogotá, and probably in other similar developing nations.

When we increase the number of days that ICU patients take to recover, i.e., $1/\gamma_U = 14$ days, rather than 7, the number of ICU beds needed almost doubles. If the probability of being an ICU patient p_U is reduced, the number of beds is reduced, but even a small increase in this probability will cause a large increase in the number of ICU beds needed during the peak of the epidemic.

5. DISCUSSION

This paper presents a prediction of the total number of ICU and regular beds that will be needed during the pandemic COVID-19 for Bogotá, Colombia. We use a SEIR model that differentiates between three types of infected patients: those who can stay at home, those who need regular hospital beds, and those who need ICU treatment. It employs a mean incubation period of 5.2 days and mean infection periods of 4 days (for patients at home), 5 days (for patients in regular hospital beds), and 7 days (for patients in ICU). The parameters assumed in the model are for a positive scenario, where the effective reproduction number during the lock-down is assumed to be 1.1, and 1.3 after the lock-down, and 1.2 when other measures are introduced. We assume that 2.6% of patients require ICU treatment, 13.4% require regular hospital beds, and the rest only require home care. The model allows for a time varying transmission rate which we use to incorporate the measures introduced by the government over the period of 1 year. The model predicts that by mid-November, 2020, the city will reach the peak of the epidemic with a total 67, 866 prevalent cases and 1,362 active ICU prevalent cases.

The number of patients that need hospitalization can surpass the current planned capacity, set at 1,200 beds for ICU beds in the city, and the death toll can reach a total of 13,268 in 6 months' time (by the end of December). The unpreparedness of the health system will only increase COVID-19 related and unrelated mortality, as already observed in Italy, the USA, and other countries. Measures like lockdown have been used in most countries to diffuse the demand for health services due to COVID-19 over time, however it may be insufficient if there are not enough resources to ramp the health services in developing nations, such as is the case of Colombia, where the need for additional resources is a priority at this point.

Other than the intrinsic limitations of SEIR models, this prediction model does not take into account the age and sex distribution of the population, but we plan to introduce such distinctions in a future version of the model with an additional mixing including the contact matrices, as the recent national population census in Colombia is available. Also, we have fitted a model with two interventions: a lockdown and mitigation measures, but this can be modified later in time. Neither do we take into account regional differences, in a tropical context relate to weather and climate, because there is no evidence, to date, whether the pattern of spread of the novel coronavirus depends on weather conditions.

Finally, we provide a Shiny app available at https://claudia-rivera-rodriguez.shinyapps.io/shinyappcovidclinic/. The original values in the app reproduce the results of this paper, but the parameters and starting values can be changed according to the user's needs.

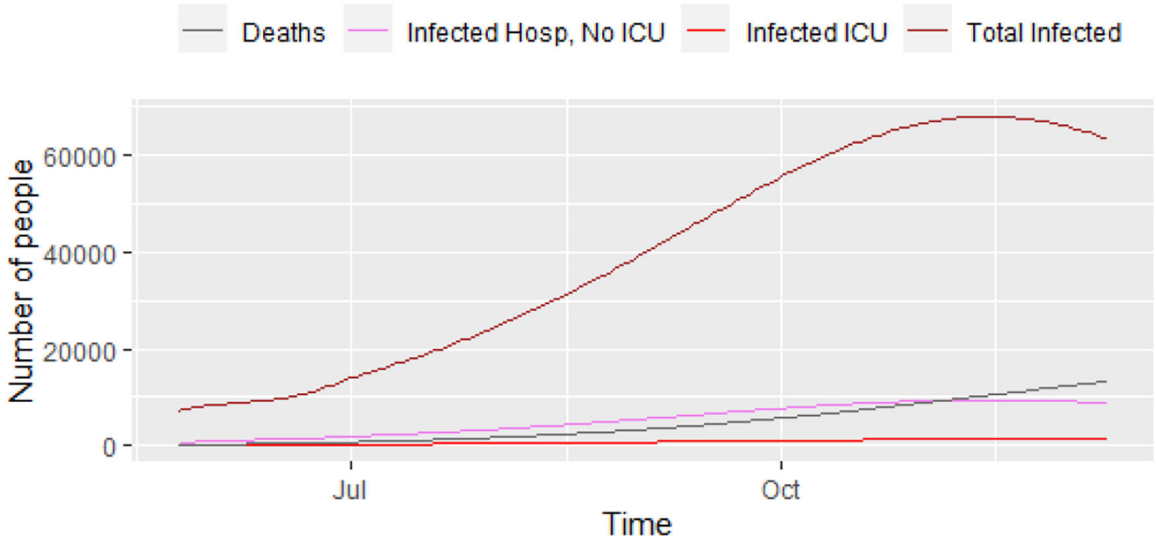

FIGURE 3 | Progress of the epidemic—infected and deaths, results from model (1).

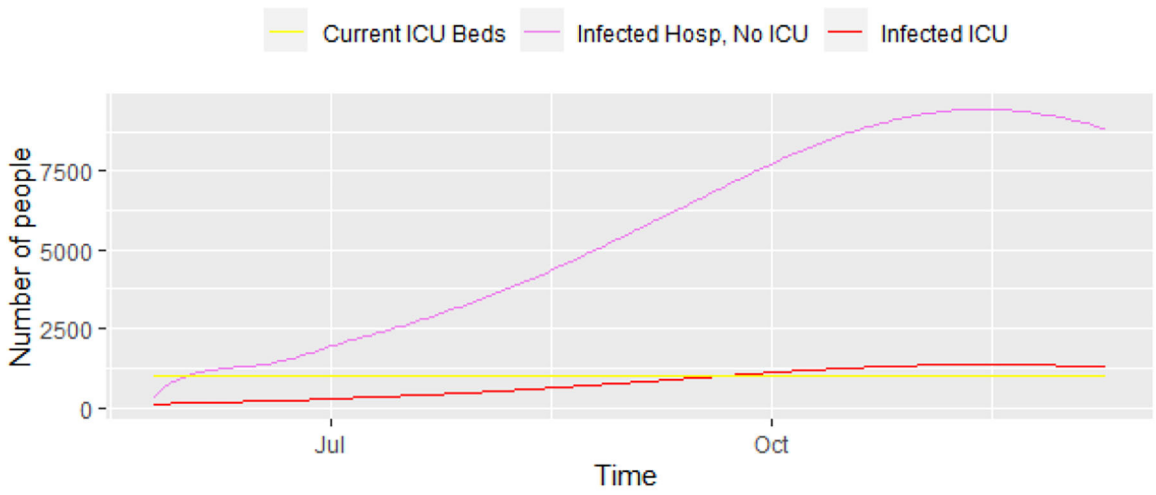

FIGURE 4 | Progress of the epidemic—infected that require ICU and infected that require regular hospital beds, results from model (1).

6. CONCLUSIONS

COVID-19 has posed too many challenges to health systems around the globe. It is remarkable that governments everywhere have swiftly responded by increasing laboratory tests, medical personnel, infrastructure, and data production linked to the disease. It is even striking that a developing nation, such as Colombia, has publicly available information updated daily on the evolution of the pandemic, with all the attendant pros and cons. Daily data is probably defective, and by now is preliminary, but still very helpful when trying to find solutions to the hard issues imposed on the demand for health resources due to the pandemic. The standard time of production of mortality data is 2 years and a trimester, according to the official national statistical office (DANE).

This model is a useful tool for cities, hospitals and clinics in Colombia that need to prepare for the excess demand of services that a situation like this imposes. The model predicts that by mid-November, the current capacity of ICUs in Bogotá will not be enough if no other measures are taken. Lock-down rules in fact were strengthened, tracking, surveillance and testing capacities also increased, and social behavior tilted toward following preventive measures. As a result, the observed reproductive numbers dramatically diminished, and when used in the model we obtain a fairly similar number of beds demanded as those actually observed, and a slightly higher mortality than observed. We expect all those measures and preventive behavior

will be maintained for the remainder of the pandemic, otherwise there will be a demand for beds that will surpass the current capacity in the city.

DATA AVAILABILITY STATEMENT

The materials(code) used and/or analyzed during the current study are available from the corresponding author on reasonable request. Additionally, a shiny app is available online at https://claudia-rivera-rodriguez.shinyapps.io/shinyappcovidclinic/.

AUTHOR CONTRIBUTIONS

CR-R contributed to the analysis and coding of the model and the shiny app. BU contributed to model interpretation and article writing. All authors have read and approved the manuscript.

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Conflict of Interest: The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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APPENDIX

REPRODUCTION NUMBER AND $\beta(T)$

We use the next generation matrix approach to find the basic reproduction number (19, 20). We estimate $\beta(t_0)$ from the basic reproduction number. To find R_0, following (4), we let $\mathbf{x} = [E, I_{\mathrm{U}}, I_{\mathrm{NoU}}, I_H]$ and $\mathbf{y} = [S, R, D]$. Disease free equilibrium is $\mathbf{x}_0 = [0, 0, 0, 0]$ and $\mathbf{y}_0 = [N, 0, 0]$. Then,

$$\mathcal{F}_{i,t}(\mathbf{x}, \mathbf{y}) = [-\beta(t_0) S \frac{(I_{\mathrm{U}} + I_{\mathrm{NoU}} + I_{\mathrm{H}})}{N}, 0, 0, 0]^T \quad \text{(A1)}$$

$$\mathcal{V}_{i,t}(\mathbf{x}, \mathbf{y}) = [(\kappa_{\mathrm{U}} + \kappa_{\mathrm{NoU}} + \kappa_{\mathrm{H}})E, \gamma_{\mathrm{U}} I_{\mathrm{U}} - \kappa_{\mathrm{U}} E, \gamma_{\mathrm{NoU}} I_{\mathrm{NoU}} - \kappa_{\mathrm{NoU}} E, \gamma_{\mathrm{H}} I_{\mathrm{H}} - \kappa_{\mathrm{H}} E]^T \quad \text{(A2)}$$

and

$$\mathbf{F} = \frac{\mathcal{F}_{i,t}(\mathbf{x}_0, \mathbf{y}_0)}{d\mathbf{x}} = \begin{bmatrix} 0 & \beta(t_0) & \beta(t_0) & \beta(t) \\ 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 \end{bmatrix} \quad \text{(A3)}$$

$$\mathbf{V} = \frac{\mathcal{V}_i(\mathbf{x}_0, \mathbf{y}_0)}{d\mathbf{x}} = \begin{bmatrix} (\kappa_{\mathrm{U}} + \kappa_{\mathrm{NoU}} + \kappa_{\mathrm{H}}) & 0 & 0 & 0 \\ \kappa_{\mathrm{U}} & \gamma_{\mathrm{U}} & 0 & 0 \\ \kappa_{\mathrm{NoU}} & 0 & \gamma_{\mathrm{NoU}} & 0 \\ \kappa_{\mathrm{H}} & 0 & 0 & \gamma_{\mathrm{H}} \end{bmatrix} \quad \text{(A4)}$$

The inverse of $\mathbf{V}$ is given by

$$\mathbf{V}^{-1} = \begin{bmatrix} \frac{1}{\kappa_{\mathrm{U}} + \kappa_{\mathrm{NoU}} + \kappa_{\mathrm{H}}} & 0 & 0 & 0 \\ -\frac{\kappa_{\mathrm{U}}}{\gamma_{\mathrm{U}}(\kappa_{\mathrm{U}} + \kappa_{\mathrm{NoU}} + \kappa_{\mathrm{H}})} & \frac{1}{\gamma_{\mathrm{U}}} & 0 & 0 \\ -\frac{\kappa_{\mathrm{NoU}}}{\gamma_{\mathrm{NoU}}(\kappa_{\mathrm{U}} + \kappa_{\mathrm{NoU}} + \kappa_{\mathrm{H}})} & & \frac{1}{\gamma_{\mathrm{NoU}}} & 0 \\ -\frac{\kappa_{\mathrm{H}}}{\gamma_{\mathrm{H}}(\kappa_{\mathrm{U}} + \kappa_{\mathrm{NoU}} + \kappa_{\mathrm{H}})} & 0 & 0 & \frac{1}{\gamma_{\mathrm{H}}} \end{bmatrix} \quad \text{(A5)}$$

thus

$$\mathbf{F}\mathbf{V}^{-1} = \beta(t_0) \begin{bmatrix} -\frac{\gamma_{\mathrm{NoU}}\gamma_{\mathrm{H}}\kappa_{\mathrm{U}} + \gamma_{\mathrm{U}}\gamma_{\mathrm{H}}\kappa_{\mathrm{NoU}} + \gamma_{\mathrm{U}}\gamma_{\mathrm{NoU}}\kappa_{\mathrm{H}}}{\gamma_{\mathrm{U}}\gamma_{\mathrm{NoU}}\gamma_{\mathrm{H}}(\kappa_{\mathrm{U}} + \kappa_{\mathrm{NoU}} + \kappa_{\mathrm{H}})} & 1/\gamma_{\mathrm{U}} & 1/\gamma_{\mathrm{NoU}} & 1/\gamma_{\mathrm{H}} \\ 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 \end{bmatrix} \quad \text{(A6)}$$

The spectral radius of $\mathbf{F}\mathbf{V}^{-1}$ is

$$\rho(\mathbf{F}\mathbf{V}^{-1}) = R_0 = \beta(t_0) \left| \frac{-\gamma_{\mathrm{NoU}}\gamma_{\mathrm{H}}\kappa_{\mathrm{U}} - \gamma_{\mathrm{U}}\gamma_{\mathrm{H}}\kappa_{\mathrm{NoU}} - \gamma_{\mathrm{U}}\gamma_{\mathrm{NoU}}\kappa_{\mathrm{H}}}{\gamma_{\mathrm{U}}\gamma_{\mathrm{NoU}}\gamma_{\mathrm{H}}(\kappa_{\mathrm{U}} + \kappa_{\mathrm{NoU}} + \kappa_{\mathrm{H}})} \right| = \beta(t_0)\tau \quad \text{(A7)}$$

Using this, we find that

$$\beta(t_0) = \left| \frac{\gamma_{\mathrm{U}}\gamma_{\mathrm{NoU}}\gamma_{\mathrm{H}}(\kappa_{\mathrm{U}} + \kappa_{\mathrm{NoU}} + \kappa_{\mathrm{H}})}{-\gamma_{\mathrm{NoU}}\gamma_{\mathrm{H}}\kappa_{\mathrm{U}} - \gamma_{\mathrm{U}}\gamma_{\mathrm{H}}\kappa_{\mathrm{NoU}} - \gamma_{\mathrm{U}}\gamma_{\mathrm{NoU}}\kappa_{\mathrm{H}}} \right| R_0 \quad \text{(A8)}$$

When $R_0 = 1.1$, $\beta(t_0) = 0.22$. Our rationale for choosing $\beta(t_1)$ and $\beta(t_2)$ is as follows.

Using the initial β_0, we calculate $S(t_1)/N$, and we assume that $R(t) = 1.3$ for $t_1 \leq t \leq t_2$, and $R(t) = 1.1$ for $t > t_2$.

To find $\beta(t)$, we assume that $R(t) \approx \beta(t) * \tau S(t)/N$. So, we have that $\beta(t) \approx R(t) * N/(\tau * S(t))$ So, we have $\beta(t) = 0.26$ for $t_1 \leq t \leq t_2$, and $\beta(t) = 0.24$ for $t > t_2$.

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Role of Railway Transportation in the Spread of the Coronavirus: Evidence From Wuhan-Beijing Railway Corridor

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The last few months have marked a notable surge in COVID-19. The disease has infected 10 million people around the world and has gained attention in the field of research. Allegedly originating in China, the virus has spread to nearly every country. The current study aims to analyze the potential spread of the coronavirus through rail transport by considering the case of the Wuhan-Beijing railway corridor in China. It has been found that approximately 43,000 people travel daily through this railway line, which indicates a high chance for this railway line to spread the virus. This study adopts a quantitative methodology to analyze the spread of the disease due to a large number of people traveling on the Wuhan-Beijing railway line. The findings of this study establish that the railway line leaving Wuhan carries approximately 43,000 people daily. The more people travel, the higher the chances are for the spread of the disease through this railway line. In line with that, the study has also analyzed the effectiveness of control measures such as lockdown, the use of masks, sanitization, and social distancing for railway authorities as well as passengers. This study concludes by proposing new practical recommendations for further controlling the spread of the disease in Wuhan.

Keywords: COVID-19, COVID, coronavirus, railway, transportation, corridor

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INTRODUCTION

Over the past few months, the world has experienced a massive outbreak of a novel coronavirus (COVID-19), which is believed to have originated in Wuhan, China. The exact source of the virus is, however, still unclear but health officials have identified that the virus immediately spreads from person to person when an infected person coughs or sneezes close to another person. Since December 2019, the virus has caused nearly 3,300 deaths in China (Jung et al., 2020). Outside China, the virus has spread to approximately 200 countries around the world and studies like (Lu et al., 2013) and (Yang et al., 2020) report that the outbreak has now been designated a global pandemic, which is justified by its spread around the world. The pandemic has resulted in many countries imposing strict lockdowns. The governments of all countries have been taking serious steps to minimize the spread of the disease. Hence, it can be stated that researchers and healthcare authorities are working hard to not only identify the causes of the virus but its cure too.

It has been reported that the spread of the virus has been most severe in China. The BBC has reported that the coronavirus is still spreading throughout the country. Researchers and specialists have spent a great amount of time trying to identify the causes of the disease in China, but this is still not clearly known. Although a careful assessment of the disease has resulted in recognizing the methods responsible for the spread of the disease. For instance, researchers (Cascella et al., 2020) revealed that the disease spreads by a lack of distance between people. Similarly, another study analyzed (Peeri et al., 2020) how the virus transfers by physical contact between people, such as through handshakes and hugs. The findings of a study by Ayittey et al. (2020) identified the objects through which coronavirus is likely to spread, such as handrails, telephones, and door handles. The Guardian also supports this finding by stating that banknotes, door handles, and handrails are the most significant objects that transmit the disease from one person to another. This implies that places which are densely packed have the highest probability of contributing to the spread of the coronavirus. Among other places, railway stations have been ignored in the literature, which is why this study assesses the spread of the coronavirus through rail transport by considering the example of the Wuhan-Beijing railway line.

Background

With its massive outbreak, the disease has gained attention in the field of research too. Various researchers like (Balkhair et al., 2017), (Anthony et al., 2017), and (Wang et al., 2020) have dedicated studies to analyze the causes, impacts, and control measures of the coronavirus. Moreover, scholars are also attempting to carefully gauge the spread patterns of the disease so that they can be controlled. But the existing research fails to acknowledge the spread of the disease through railway transport in China. The last decade has marked a massive growth in rail transport in the country with about 3.4 billion people traveling by train in 2018. It is, therefore, essential to identify the transmission of the disease through this form of transport. This study seeks to investigate how increasing movement of people through the railway in China plays a significant role in the spread of the coronavirus. About 440 million people traveled using Wuhan's railway line for China's New Year festivities, the spread of the disease was evident (Wong, 2019). Therefore, the focus of this study has been narrowed down to evaluate the spread of the coronavirus through the Wuhan-Beijing railway line.

Research Questions

The findings of this study will address the following research questions:

- How does high dependence on rail transport spread the coronavirus in different cities of China?
- What is the effectiveness of the current practices and control measures for the spread of the coronavirus?
- What are the strategies to control the spread of the coronavirus through rail transport in Wuhan and Beijing?

PREVIOUS STUDIES

Since this topic is gaining increasing attention in the research frontier, it is essential to review what has already been reported so far. Thus, this section reviews previous studies on the topic.

Spread Patterns of the Coronavirus in China

Studies recognize the first known case of the coronavirus to be on December 1, 2019, in Wuhan, Hubei, after which the cases continued to increase (Zhao et al., 2020b). Ever since, the virus has spread not only through the province but throughout the whole of China too. In view of the initial spread of the disease in Wuhan, the focus of this research is also Wuhan. China is identified as the most populous country in the world. Wang reports that the country had a population of approximately 1.39 billion in 2018 with an area of 8,494 km^2, as shown in **Figure 1** (Wang, 2019). Wuhan, with a population of 11 million people is the seventh most populated city in China. As **Figure 1** shows, Wuhan is located in the middle of China, has a convenient transport system, and so it is possible to assume that the virus can be spread to all of China from Wuhan as the center of the breakout, as shown in **Figure 2**.

Relating that with the coronavirus, it can be seen that a massive number of people are likely to be infected in the country. This also indicates the uncontrolled spread of the disease in China, compared to other countries (see **Figure 3**). The figure also shows the pattern of the disease across January, March, and May. **Figure 2** highlights the massive number of coronavirus cases to be identified in Wuhan (as shown by number and dots). The total number of cases confirmed by the Chinese authorities jumped to 4,515 on January 27, which shows an immense increase from 1,680 cases from the previous day (BBC China, 2020). This uncontrolled outbreak forced the government and health authorities in China to take multiple steps to control the disease, such as lockdowns, the ban on movement of people and transport, and a strict prohibition on public gatherings. Due to these drastic measures, the spread of the virus was controlled in the country, ultimately resulting in no new reported cases in the middle of March. Bloomberg News reports that with the passage of time, the country witnessed a gradual decrease in the number of cases identified and an increase in the number of recovering people (Bloomberg News, 2020).

Rail Transport and the Spread of the Coronavirus

With an emerging volume of research being dedicated to the spread of the coronavirus, researchers are attempting to identify the causes of the disease too. In this regard, researchers and officials have discussed the various objects which can contribute to the spread of the disease, such as those stated before. Objects used by multiple people, for instance, coffee machines in an office, ATM machines, and bathroom surfaces, contribute to the spread of the disease. Given the current situation, governments and authorities have put a strict ban on transport mechanisms (Ranasinghe et al., 2020). This situation can be justified by the

FIGURE 1 | China map (highlighted area showing Wuhan).

fact that transport vehicles, specifically trains and buses, spread the disease to a large extent. Otter et al. (2016) explains this fact by showing that, among other materials, plastic, and steel contribute significantly to the spread of the disease. The New England Journal of Medicine reported that the coronavirus can survive on materials like plastic and steel for as long as 72 h, cardboard for approximately 24 h, and copper for an estimated 4 h (Pasley, 2020). This does not imply that these objects spread the virus; instead, that interaction with these objects and then touching the face does.

By relating these findings back to the transport mechanism, it can be stated that the infrastructure of transportation relies heavily on these materials. When people use transport services, such as the railway, they are highly likely to be contaminated with the virus. This can be explained by the increasing use of handrails and ticket machines, which is why authorities disinfect them from occasionally. Shen et al. (2016) reports that rail transport are a highly popular mode of transport, with a high density of people. Since the virus spreads by the close proximity of people, the chances for the disease to rise are evident through rail transport (Shen et al., 2016). Goscé and Johansson (2018) add to these findings and state that people traveling through underground railways are prone to influenza-like diseases, which can later lead to the coronavirus. Some underground railway lines are densely packed with people, which also indicates the rise of the virus due to the lack of distance between people. Apart from people at railway stations, people living in nearby areas are also prone to the virus because of its contagious nature. This also justifies the strict lockdowns and bans on rail transport by governments in different countries. The research in this dimension concerning the spread of the virus is rare, which justifies the focus of the current study.

Given the significance of rail transport, the literature needs to pay attention to the spread of the coronavirus through transport. For instance, Wong (2019) reported on the increasing dependence of people on rail transport in China. Other studies like (Ranasinghe et al., 2020) add to these findings and state that people in China find it feasible to travel within cities through high-speed rail networks. The significance of the railway network in Wuhan is specifically emphasized because it is the hub of transportation in Hubei province. While researchers highlight the significance of rail transport and dependence on it, they are yet to investigate the spread of coronavirus due to this dependence. This research seeks to fill this gap in light of the existing literature. This study will be helpful for policymakers and the management authorities of Wuhan railway stations since it will highlight how the spread of the disease can be controlled.

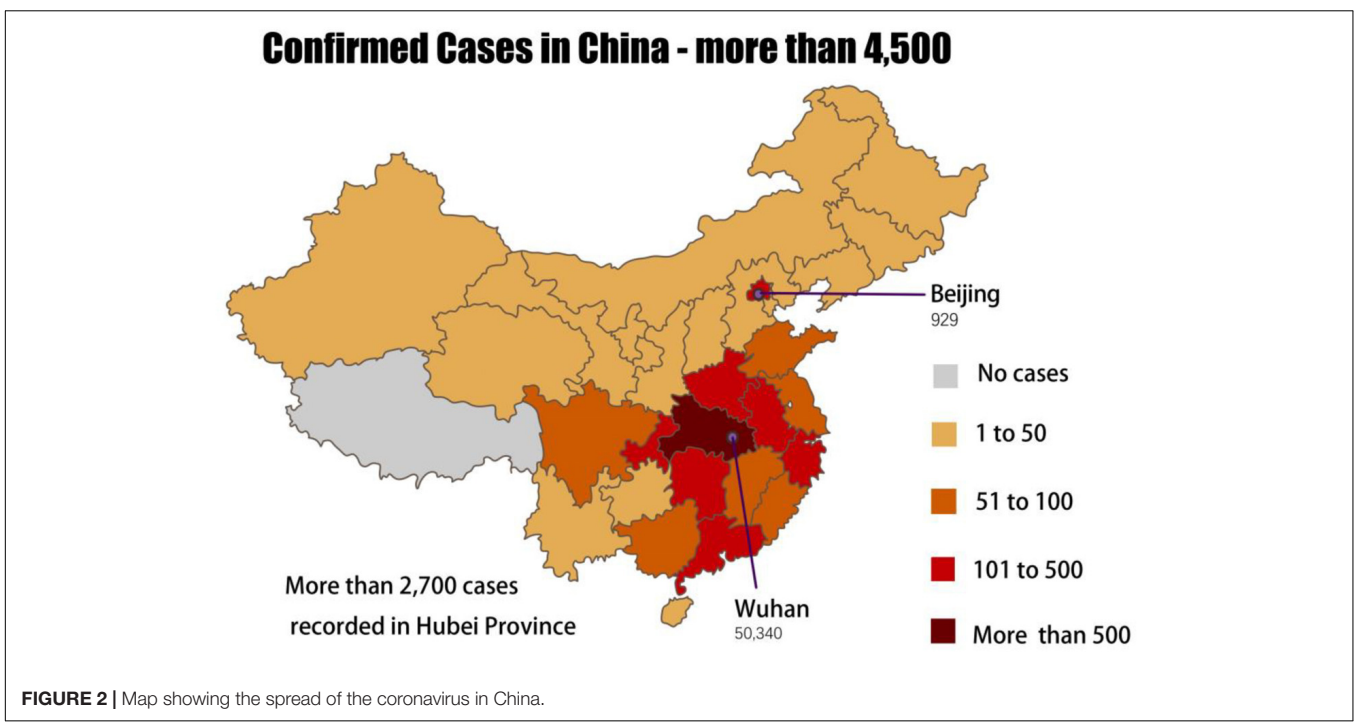

FIGURE 2 | Map showing the spread of the coronavirus in China.

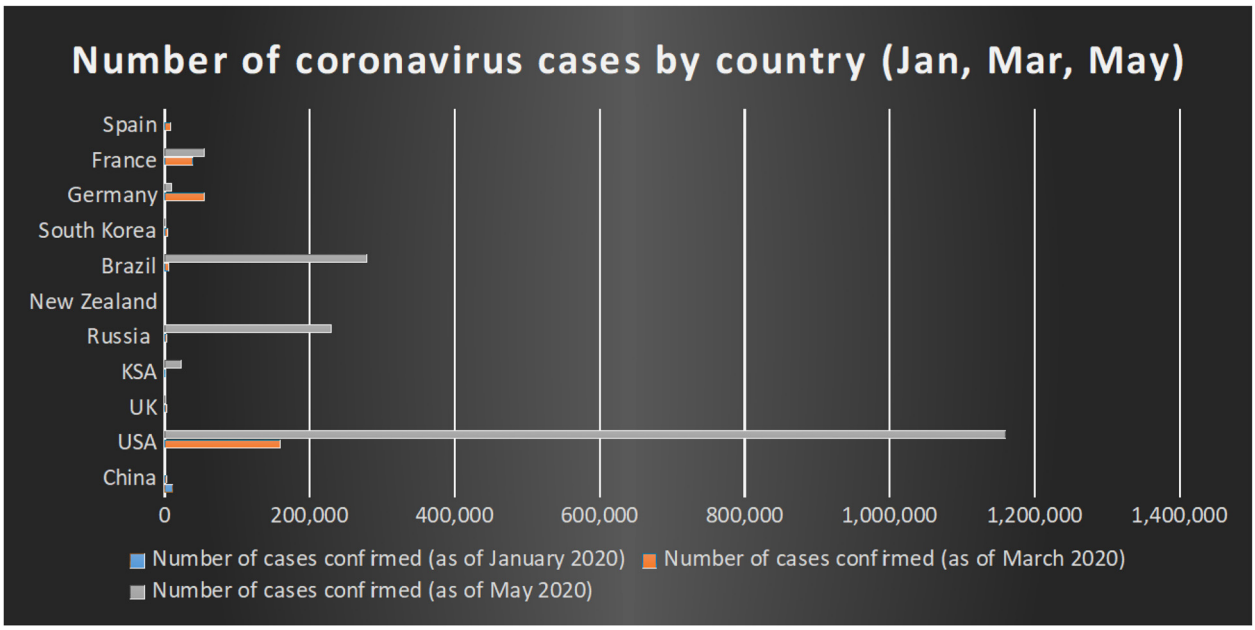

FIGURE 3 | Situation of the spread of the coronavirus in China (Self-drawn).

METHODOLOGY

Designing an effective methodology is of core significance to generate high-quality research results. Thus, this section highlights the methodological foundations of the current study.

Research Method

The current research uses quantitative methods which are assumed to generate credible and objective findings. As the question at hand is of core importance, it is essential for the researcher to generate undistorted and authentic findings. A qualitative research method was not used to gauge the spread of the coronavirus through the railway because this method takes time and is likely to be misinterpreted by the researcher (Tracy, 2019). Thus, a quantitative method was used to gauge the number of people traveling along the Wuhan-Beijing railway line and the consequent spread of the disease. In line with the chosen method, this research makes use of positivist philosophy. Through this philosophy, this research generates credible and reliable results about the spread of the coronavirus through rail transport in China. Although interpretivism can also be used for this research, positivism was chosen, to save time for the research. Positivist philosophy is also preferred because it keeps the researcher detached from the findings of this study. Care has been taken in order to make the findings regarding the spread of the coronavirus through railway stations meaningful and objective.

This methodology makes use of a deductive approach. The choice of approach can primarily be justified by the fact that a large volume of data already exist on this topic, which can be analyzed to gauge the spread of the coronavirus in China. The inductive approach would have been preferred if the research lacked any theories or testable hypotheses regarding the spread of the coronavirus in China, as also analyzed by Liu (2016). In view of the problem at hand, the appropriateness of the deductive approach is justified because only through this approach is the researcher able to empirically identify whether the coronavirus spreads through rail transport and to what extent.

Sampling

Multiple sampling techniques can be used to draw a representative sample for study. The current study relies on a random sampling technique. This technique made it easier for the researcher to select the sample respondents as per his ease. The sample respondents include railway station officials at Wuhan, who are aware of the Wuhan-Beijing railway route as well as the number of people traveling through it. Through a random sampling technique, the researcher selected a sample of 50 respondents from the administrative body of Wuhan railway station. The use of a sample of this size is justified by Heydari and Mountrakis (2018).

Data Collection Strategy and Method

The current study relies on primary data through survey questionnaires, which railway station officials in Wuhan completed. Since there is little to no evidence about the spread of the coronavirus, specifically through rail transport, collecting primary data is essential and justified. Different strategies are used for the collection of fresh data, out of which surveys have been used in this study. In accordance with the quantitative approach and positivist philosophy, the research relies on quantitative surveys (Bramley et al., 2018). A five-point Likert scale questionnaire was designed to collect data from railway officials at Wuhan railway station. Since the scope of this research is limited to the Wuhan-Beijing railway line only, questions will

relate to the number of people traveling by rail from Wuhan to Beijing before the spread of the coronavirus, the number of cases reported as a result of that travel, and areas where the disease has spread as a result. The use of quantitative surveys is justified for this research since this strategy has allowed the researcher to gain a considerable amount of data in a comparatively short time (Clifton and Carrasco, 2018). This would not have been possible using other research strategies, like interviews and observations. The data collected has then been analyzed using descriptive analysis techniques, so as to provide a summary of the key findings regarding the spread of the coronavirus through railways in China.

Ethical Considerations

When collecting the data, the researcher has been cautious about sustaining the ethical standards for conducting research. In this regard, the researcher has taken care not to use any forceful techniques to collect data. Moreover, all the respondents were given the right to withdraw from the study at any point. As per the recommendation of Tourangeau (2018), the researcher has taken special care to maintain the confidentiality and anonymity of the respondents. Besides this, care has been taken to avoid the misuse of data collected. The studies used for the literature review have been cited appropriately. In this way, the ethical standards required for this research have been assured.

RESULTS AND DISCUSSION

The data collected through primary means has been analyzed using descriptive analysis. This section is dedicated to illustrating and discussing the key findings from the primary data. In order to extract useful meanings from the findings, the discussion is built by relating the findings of primary data with those from the existing body of knowledge.

Results From Primary Data

Age and Experience of Respondents

This section examines the age and experience of respondents to analyze the characteristics of the sample. The demographic analysis of a sample is useful to ensure that a suitable and respectable sample has been selected. **Figures 4A,B** highlight that all of the respondents are 30 years or older and have a working experience of more than 3 years. Paradis et al. (2016) highlights that experienced respondents are likely to give better responses, especially about a global issue like the coronavirus, hence the selection of these respondents is evidence of the validity of the responses.

Effectiveness of Control Measures

In view of the massive spread of the disease in China, authorities at the government and private level are taking effective measures to control its spread. It has been found that the coronavirus started in December 2019 in Wuhan and spread rapidly in the city (Ayittey et al., 2020). With a population of approximately 11.08 million people, Wuhan is one of the most populous cities in China. In addition this, the city is also a key transportation hub in China. This implies that due to the massive number of residents, along with the movement of people from nearby cities, the chances of the spread of the disease are automatically amplified. Given these facts, authorities and the management of Wuhan railway station have taken multiple steps to control the spread of the disease. For example, the authorities complied with the regulations regarding lockdown and banned rail transportation to and from Wuhan (BBC China, 2020). As soon as the epidemic spread, the Wuhan government banned all modes of transportation to and from the city, including the railway, ferries, subways, city buses, and long-distance shuttle buses. After lifting the lockdown, the railway authorities imposed several restrictions to ensure that the disease remained controlled in the city. These restrictions included wearing masks, using sanitizers frequently, and maintaining social distance. The BBC reported that even after lifting the lockdown, only those with health clearance certificates were allowed to use the train service. According to the primary data collected here, it can be stated that a notable number of respondents agree with the fact that these practices are effective in controlling the spread of the disease (see **Figure 5A**). However, some of the respondents disagreed with the economic burden that lockdown created on the railway transport sector. With a massive number of people depending on the Wuhan railway network, the economic hit on this sector was notable. For instance, the lockdown resulted in an abrupt drop in the profits to Wuhan railway station. Studies refer to the loss of jobs in China as a result of the coronavirus and that implication is evident in Wuhan too. By combining these findings, it can be stated that although the measures taken by the railway authorities are deemed as impractical by some people, they are effective in the long run until the city is declared completely free from the virus.

Similarly, the primary data collected for this study has gauged the effectiveness of these control measures for the customers. As evident in **Figure 5B**, the majority of respondents agree with the fact that control measures like lockdown, the use of masks, sanitization, and social distancing are effective for the safety of passengers in this pandemic. The resistance of people to these control measures can be justified by the fact that lockdown has hindered a number of life events and day-to-day activities and people are forced to stay in their homes. However, the majority of the respondents agree that these control measures are effective in controlling the massive spread of the disease. People in Wuhan have been psychologically disturbed by the pandemic, which is why they are willing to comply with the regulations imposed by the government and railway authorities. It is only due to this compliance that the number of coronavirus cases in Wuhan has reduced significantly in the past few days. News reports show that in July, only four new cases were diagnosed, which were all imported from other countries. Hence, it can be deduced that control measures have been effective in controlling the spread of the disease in China.

Figures 6A,B show the amount of acknowledgment of the coronavirus by the people in Wuhan and the reduced passenger flow to and from the city. With reference to **Figure 6A**, it can be stated that almost all the respondents acknowledge the rapid spread of the coronavirus. As stated earlier, people in

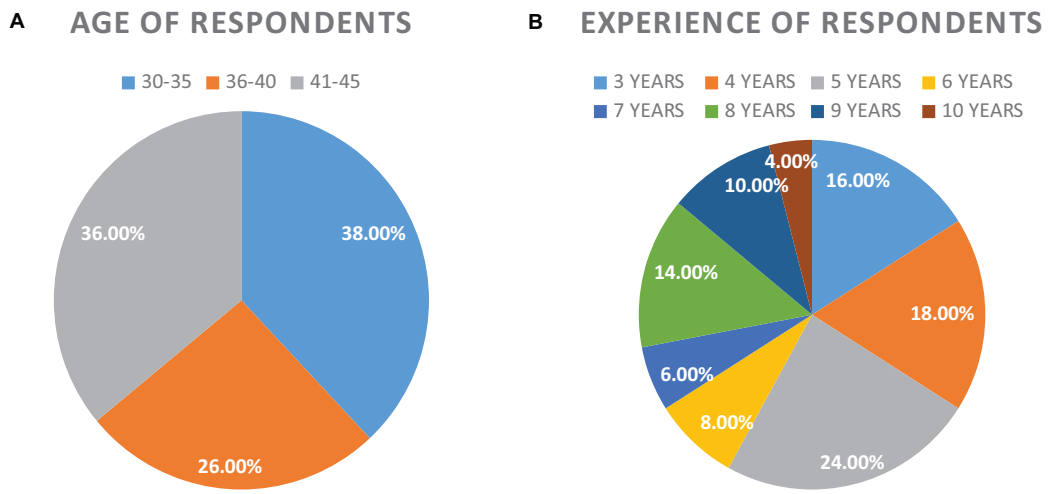

FIGURE 4 | Analysis of respondents in terms of age/experience.

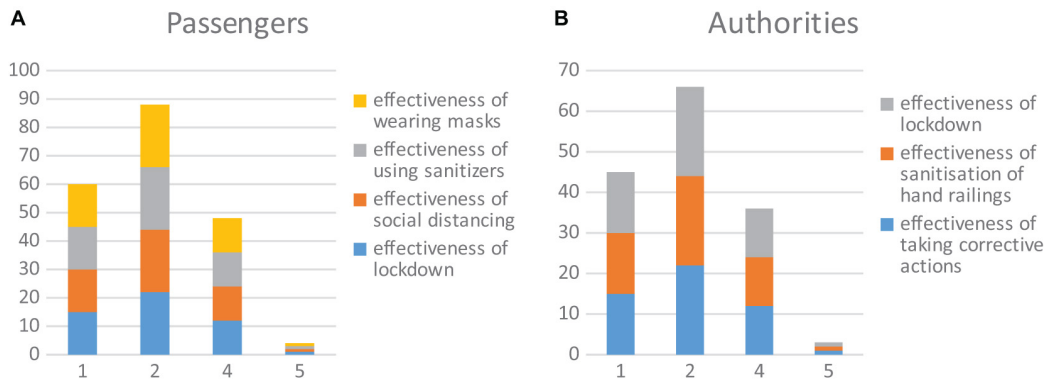

FIGURE 5 | Effectiveness of control measures taken by passengers **(A)** and authorities **(B)** of the Wuhan-Beijing railway line.

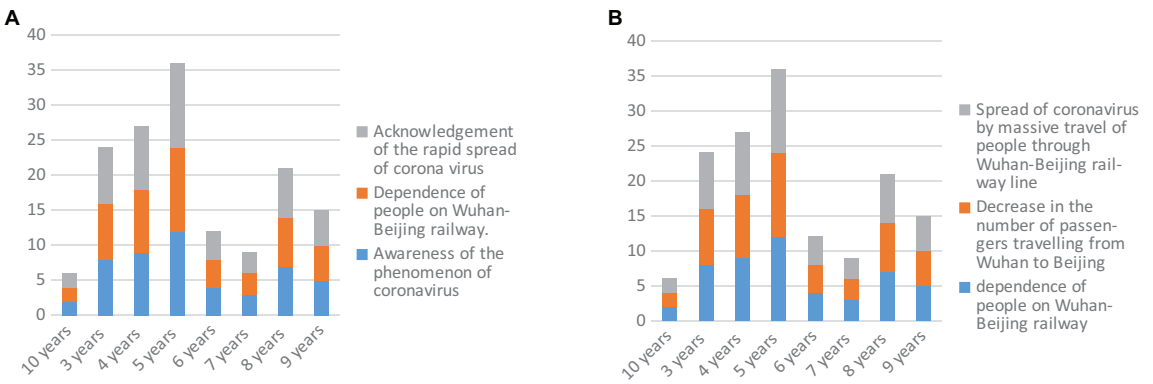

FIGURE 6 | (A) Acknowledgment of the respondents and **(B)** passenger flow on the Wuhan-Beijing railway line.

Wuhan significantly depend on rail transport, which is why railway transport heavily contributes to the spread of the disease. Given the increasing number of cases and consequent deaths, the flow of railway passengers has been reduced to a notable degree (see **Figure 6B**). The lockdown and control measures imposed by the railway authorities have been effective. Further, people in Wuhan also realize the negative connotations of the disease and thus comply with the ban on transport. It is due to

this acknowledgment that the number of coronavirus cases and deaths in Wuhan has gradually decreased.

Discussion

The findings, in relation to the existing literature, show that the Wuhan-Beijing railway line starts from Wuhan and passes through Beijing, Guangzhou, Shenzhen, and Hong Kong (Hu et al., 2017). Apart from that, respondents reveal that approximately 43,000 passengers normally travel through this railway line every day. This is found to be in accordance with the findings of Li and Sheng (2016), who also state that this railway line is the busiest in China. By relating the findings from primary and secondary sources, it can be established that the massive number of people traveling daily through the busiest railway line in China may become carriers of the disease in all the connecting cities. The Wuhan-Beijing railway line passes through four cities. The intermixing of people across these cities suggests a rapid transmission of this disease, which is why the cases continued to increase from December 2019 to February 2020 (**Figure 1**). Thus, it can be stated that railways play a considerable role in the rapid transmission of the disease.

Before the government of China and the railway authority of Wuhan imposed restrictions on travel, the number of cases continued to rise. Extant studies report that Wuhan is known for the high number of passengers entering and leaving the city. It is due to this that the government of Hubei imposed a lockdown in Wuhan on January 23 2020, thereby prevent air and rail transport until further notice (Mizumoto et al., 2020). Findings from the primary data can be related to the fact that the transmission of the disease could be accredited to an increased flow of people from Wuhan to Beijing. The findings regarding the effectiveness of lockdown for railway officials and passengers can also be explained by this discussion. When the lockdown was imposed and travel from Wuhan to Beijing was banned, there was a gradual drop in the number of cases reported in China. It can be deduced that after the imposition of the strict lockdown, China experienced a break from the massive spread of the coronavirus. By combining all these findings, it can be deduced that rail transport in China has been a notable contributor to the far-reaching spread of the coronavirus. Looking at the case of the Wuhan-Beijing railway line, it can unarguably be established that the immense flow of people from Wuhan to Beijing and other connecting cities along this railway line created a surge in the number of cases reported.

In view of this discussion, the effectiveness of the control measures taken by government officials for the general public can also be established. Primary data reports that although a large number of people find practices such as lockdown, wearing masks, sanitizing hands, and social distancing effective, some still disagree with this set of restrictions, holding that finding a cure is key to battling this pandemic. What needs to be understood here is the idea that practices like social distancing and quarantine are effective in controlling the massive transmission of the disease (Katz et al., 2019). The government of China and the railway authorities of Wuhan have restricted rail travel so that the spread of the coronavirus can be controlled and the wellbeing of the general public is consequently guaranteed. Given the current situation wherein the cases of the coronavirus have reduced in China, the government of China lifted the lockdown in Wuhan and other cities. **Figure 2** highlights the cases of the coronavirus in different cities in China. By comparing this map with the one shown in **Figure 3**, it can be seen that the cases of the coronavirus in May considerably reduced.

However, the impact of this epidemic is long-lasting. In accordance with the findings of Ma et al. (2020), it can be deduced that Wuhan is no longer a transportation hub since the global epidemic has left an enduring wave of fear and social isolation among people. This indicates a need for several policy measures that the government of Wuhan should consider so as to restore the city to its previous state. Given this fact, the government of China, and especially Wuhan, should execute awareness programs for citizens. In these programs, health experts should guide the people recovering from the virus regarding their mental and psychological stability. Health experts should emphasize the positive elements of the pandemic so that anxiety, depression, and other mental health issues are reduced. In addition, the government should also devise policies to restore the economy of China (Jiao et al., 2017; Chang et al., 2020; Lai et al., 2020; Nature, 2020; Zhao et al., 2020a). In this regard, the government should specifically promote online businesses in the country. The reason behind this is the fact that people are extremely scared to go out for professional or leisure purposes, even since the epidemic has diminished (VOA News, 2020). In order to satisfy the shopping needs of the citizens, the government of China should stimulate businesses to transfer their setups to digital settings. This will create a win-win situation, wherein businesses will be able to overcome the loss they have been bearing and consumers will be able to obtain the products and services they need online.

Distance and the Spread of the Coronavirus

One of the most important aspects to note in this topic is the spread of coronavirus due to distance. It has been seen that it is due to rail transport that a considerable number of COVID cases emerged in Wuhan. But the existing research fails to acknowledge the role of distance in the spread of coronavirus disease in China. VOA News (2020) reports that the districts that are closer to the Wuhan railway station have more coronavirus cases than the ones that are farther from it (see **Figure 1**). By analyzing the matter in deeper detail, it can be stated that since railway stations, especially the one in Wuhan, are massively crowded, travelers are more likely to be infected by the virus. When they travel from the railway station into the city, they can transmit the virus to people who are in close vicinity to the railway station.

Findings from the primary data shown in **Tables 1**–**3** reveal that the spread of coronavirus can be greatly accredited to people traveling from Wuhan to other cities. By relating the findings with the existing studies, it can be evaluated that a massive movement of people from and to Wuhan and its outskirts resulted in a notable spread of the disease. Xinhua news (Xinhua, 2020) reports a prominent number of cases in the Wuchang, Jianghan, and Qiaokou districts, which are in close proximity to Wuhan railway station. This is owing to the fact that the railway line passing through Wuhan ends at Zhangzhou, which is 980 km from Wuhan. Studies report that approximately 43,000

TABLE 1 | Summary of data collection procedure (Self-drawn).

Data collection	Details
Data	Collection through questionnaires from railway station officials in Wuhan
Procedure	Administering the questionnaires through email to managers
Data use	Descriptive data analysis through frequency tables
Data alignment with research questions	Linking back the results with existing studies and research questions

TABLE 2 | Views of the respondents regarding the spread of the disease.

Experience	Awareness of the phenomenon of the coronavirus	Dependence of people on the Wuhan-Beijing railway.	Acknowledgments of the rapid spread of the coronavirus
10 years	2	2	2
3 years	8	8	8
4 years	9	9	9
5 years	12	12	12
6 years	4	4	4
7 years	3	3	3
8 years	7	7	7
9 years	5	5	5
Grand total	**50**	**50**	**50**

TABLE 3 | Passenger flow on the Wuhan-Beijing railway line and the spread of the coronavirus.

Experience	Dependence of people on the Wuhan-Beijing railway	Decrease in the number of passengers traveling from Wuhan to Beijing	Spread of the coronavirus by massive travel of people on the Wuhan-Beijing railway line
10 years	2	2	2
3 years	8	8	8
4 years	9	9	9
5 years	12	12	12
6 years	4	4	4
7 years	3	3	3
8 years	7	7	7
9 years	5	5	5
Grand total	**50**	**50**	**50**

passengers travel daily through the railway lines in Wuhan. Every train that departs from Wuhan station passes through its nearby districts, particularly Wuchang, Jianghan, and Qiaokou. It has been observed that travelers reaching Wuhan railway station take taxis to travel to their desired locations. When these taxis pass through nearby districts, chances for the spread of the disease automatically increase. This implies that the spread of the coronavirus is also dependent upon the distance between cities (see **Figure 7**). By relating the discussion with the research questions, it can be deduced that railway traffic, passing through different locations near Wuhan, plays a significant role in the spread of the coronavirus.

According to Shen et al. (2020), the virus spreads through sneezing, coughing, nasal discharge, and the touch of an infected person. This implies that when a large number of infected people pass through the nearby districts of Wuhan railway station, such as Wuchang, Jianghan, and Qiaokou, they are likely to infect the people in those districts. The spread of the disease in the three stated districts is quite high because people flow into Wuhan to pass through these districts. Even if incoming people do not stay in these areas, the fact that these three districts are very close to Wuhan justifies that these districts reflect a more critical spread pattern of the coronavirus than districts that are farther from Wuhan.

Apart from that, the distance of different cities from Wuhan also plays a role in spreading the disease to multiple locations. This can be demonstrated by using the examples of two cities that are located alongside the Wuhan-Beijing railway line: Xinyang and Anyang. It can be observed that the situation of the coronavirus in Xinyang is worse than that in Anyang. The cases reported in Xinyang are almost equal to those reported in the Wuhan province, which is even more populated than Xinyang. This massive spread in Xinyang can be accredited to the closer proximity of Xinyang to Wuhan. Singhal (2020) shows that the virus spreads through the close proximity of people. When a massive number of people gather in Wuhan, there are increased chances of them infecting people living in the nearby district of Xinyang. This discussion further affirms that the coronavirus is likely to spread over the short distance between cities and districts. Further, the spread of disease due to the short distance can also be explained by the rapid movement of people in Xinyang to Wuhan. The distance between the two cities is a mere 216 km and Wuhan is known as the most developed center in China. People drive to Wuhan from Xinyang on a daily basis. The chances for the disease to spread between the two cities are evident because any infected population in Wuhan, having interacted with anyone from Xinyang, can transmit the disease to Xinyang. The argument, therefore, shows that the short distance between Wuhan and Xinyang is one of the reasons for the spread of the coronavirus in Xinyang.

Summary of Findings

To summarize, it can be deduced from the findings that railway platforms play an important role in the spread of the coronavirus. This study shows that among other reasons, the spread of the virus in China is due to the distance between the cities and people traveling among different cities through the railway. Wuhan is known to be the most populated province of China and Hubei is identified as a hub of traveling and transport in the country. The railway line leaving Wuhan carries approximately 43,000 passengers daily to different cities. The large amount of people traveling from Wuhan to nearby cities results in the spread of the disease to these cities and nearby areas too. However, the findings also report on the effectiveness of control measures taken by the railway authorities. It can be deduced from the findings of this study that measures such as lockdown, the use of masks, sanitization, and social distancing have been proven

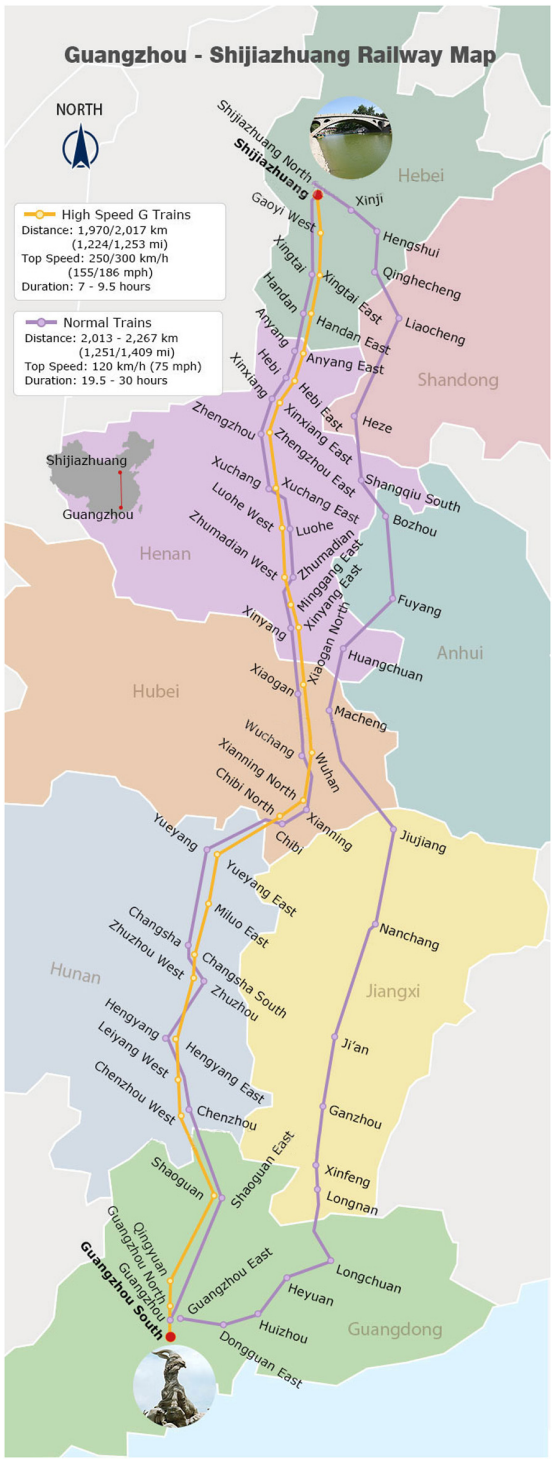

FIGURE 7 | Demonstration of areas with high prevalence of the coronavirus (Travel China Guide, 2020).

to be beneficial for controlling the spread of the coronavirus in China. In line with this, the next section highlights practical recommendations so that the disease could be controlled further.

CONCLUSION AND RECOMMENDATIONS

It has been shown in this study that Wuhan is located in one of the most populous provinces, which is an indicator of the quick spread of the disease in this city. Although the topic of the coronavirus is gaining increasing significance in the body of research, there lies a gap in analyzing the spread of the disease through rail transport in China. This is why the current study has adopted a case-study approach to evaluate the topic, considering the case of the Wuhan-Beijing railway line. Findings from the literature reveal a notable concentration of coronavirus cases in Wuhan (Ranasinghe et al., 2020). Apart from its large population, the notable inflow and outflow of people in Wuhan are a big reason for the spread of the disease. In addition to that, the current study has collected data through primary sources from experienced railway officials. Findings from the primary data are found to support the extant studies, except at particular points. It has been shown that transport through the Wuhan-Beijing railway line has contributed significantly to the spread of the disease. The imposition of lockdowns and the emphasis on practices such as social distancing and wearing safety masks are found to be effective in protecting people from the disease. However, findings reveal an evident abnormality in Wuhan even after lifting the lockdown, and so authorities should consider the following recommendations, so that the physical and mental wellbeing of the people is guaranteed.

- After the lockdown, an immense outflow of people from Wuhan is expected. Studies (Saadat et al., 2020) report that around 55,000 people were expected to leave Wuhan once the lockdown was lifted. In order to sustain the low figures of the coronavirus, the railway authorities should still keep in consideration the practices of social distancing. The authorities should be cautious of the times when the railway stations are likely to be packed and expand their infrastructure in a way that the expected outflow of people can be handled while maintaining a safe distance between passengers. It has also been shown that even after the cancellation of lockdown, the railway authorities should continue taking protective measures (Khan et al., 2020).
- The railway officials should ease the fears of the people by posting motivating signboards at different places in railway stations. Given the most unexpected outcomes of the pandemic, people will be scared to move across different cities. Thus, the railway authorities should follow the recommendation of Fine and Rajput (2020) and spread smiles for people who have survived the crisis.
- The railway authorities should install a system of testing for coming to railway stations. Although the government mandated measuring temperatures of people moving during the lockdown, a test should be done so that any person with symptoms of the coronavirus could be deterred from entering the premises or traveling through the railway. Besides this, the authorities should make sure that people wear masks and sanitize themselves regularly. The authorities should be considerate about installing hand

sanitizer and free masks at different spots in the railway station, as well as in trains. This way, the chances for the coronavirus to spread again will be minimized.

- Although the lockdown has been lifted in Wuhan, there are only a few people on roads and on public transport. This can be accredited to the wave of fear that this pandemic has left among people. In order to comfort passengers, the railway authorities should share public service messages using the most popular media like TV ads and WeChat. As also recommended by researchers (Hunter et al., 2016), sharing encouraging messages with the people surviving the crisis will help build positivity among them. The city which was once a metropolitan hub is now deserted and destitute. While the economic shock is harsh, societal wellbeing has also been harmed, and needs to be restored.

By acting upon these recommendations, the government of Wuhan and the railway authorities will gradually overcome the shock that the coronavirus has caused. The ultimate aim of the railway authorities should be to sustain not only their economic profits but the wellbeing and betterment of their society too.

Strengths and Limitations of the Study

The study has quantitatively emphasized the role of railway platforms in the spread of the coronavirus in China. The key strengths of this study include the reliance on primary data, the use of a quantitative methodology, and the production of credible findings. Having used the quantitative method, the findings of this study are generalizable too. Moreover, the study has taken into account a rather untapped area of research. Given the extant literature, it is evident that the research is scarce on the role of railway platforms in the spread of the coronavirus in China. Thus, this study has attempted to bridge this gap while further extending the literature too. The recommendations proposed in this study also play a part in controlling the spread of this disease in China. However, there are also several limitations. For instance, there are several objective and unavoidable errors in the methodological choices of the study. Given the ethical considerations, the researcher could not force any respondent to participate in the study. This resulted in some missing answers from the respondents. Moreover, the sample respondents, who were the managers at Wuhan railway station, submitted their responses in a rush due to their busy schedules. Due to the evident situation of the pandemic, the researcher could not meet the respondents in person, which indicates a chance for the responses to be inaccurate. In addition to this, the sample size taken for the study is not an accurate and realistic representative of the entire population. Although the data collected from this sample size has resulted in the support of the objectives, the findings are not as comprehensive as they could have been in the case of a larger sample size. Apart from the methodological choices, another key limitation was the limited scope of the study. The researcher centered the findings on Wuhan railway station only. However, the study could have covered other nearby railway stations and the flow of people from those areas too. Nonetheless, the researcher has tried to deduce high-quality findings by respecting all the ethical standards.

DATA AVAILABILITY STATEMENT

The original contributions presented in the study are included in the article/supplementary material, further inquiries can be directed to the corresponding author.

ETHICS STATEMENT

Ethical review and approval was not required for the study on human participants in accordance with the local legislation and institutional requirements. Written informed consent from the participants was not required to participate in this study in accordance with the national legislation and the institutional requirements.

AUTHOR CONTRIBUTIONS

RL and DL: data collection, conceptualization, investigation, methodology, simulation, and writing – original draft preparation. SK: supervision, project administration, funding acquisition, conceptualization, methodology, and writing – review and editing. All authors contributed to the article and approved the submitted version.

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Individual Behaviors and COVID-19 Lockdown Exit Strategy: A Mid-Term Multidimensional Bio-economic Modeling Approach

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As of mid-2020, eradicating COVID-19 seems not to be an option, at least in the short term. The challenge for policy makers consists of implementing a suitable approach to contain the outbreak and limit extra deaths without exhausting healthcare forces while mitigating the impact on the country's economy and on individuals' well-being. To better describe the trade-off between the economic, societal and public health dimensions, we developed an integrated bioeconomic optimization approach. We built a discrete age-structured model considering three main populations (youth, adults and seniors) and 8 socio-professional characteristics for the adults. Fifteen lockdown exit strategies were simulated for several options: abrupt or progressive (4 or 8 weeks) lockdown lift followed by total definitive transitory final unlocking. Three values of transmission rate (Tr) were considered to represent individuals' barrier gesture compliance. Optimization under constraint to find the best combination of scenarios and options was performed on the minimal total cost for production losses due to contracted activities and hospitalization in the short and mid-term, with 3 criteria: mortality, person-days locked and hospital saturation. The results clearly show little difference between the scenarios based on the economic impact or the 3 criteria. This means that policy makers should focus on individuals' behaviors (represented by the Tr value) more than on trying to optimize the lockdown strategy (defining who is unlocked and who is locked). For a given Tr, the choices of scenarios permit the management of the hospital saturation level with regard to both its intensity and its duration, which remains a key point for public health. The results highlight the need for behavioral or experimental economics to address COVID-19 issues through a better understanding of individual behavior motivations and the identification of ways to improve biosecurity compliance.

Keywords: bioeconomic model, public health, SIR, COVID-19, policy simulation

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INTRODUCTION

Coronavirus disease 2019 (COVID-19) represents a change in paradigm for our society and the health care system. In recent decades, outbreaks have been maintained locally and have been limited over time, which makes COVID-19 a novel entity (1). As of mid-2020, eradicating a disease such as COVID-19 seems not to be an option, at least in the short term. The challenge for policy makers consists of implementing a suitable approach that contains the outbreak, limits extra

deaths, and avoids the exhaustion of healthcare forces while mitigating the impact on the country's economy and on individuals' well-being (2). This means considering several competing objectives at the same time and continuously adapting the strategy and rules. The situation represents an economic dynamic optimization problem under constraint in an uncertain environment. Bioeconomic sequential optimization may help to find the best middle-term solutions that integrate the compromises between competing criteria. Epidemiologic and bioeconomic modeling provide a scientific background for evidence-based policy to be implemented in the societal, economic, and public health dimensions.

The constraints linked to COVID-19 arise both from the characteristics of the outbreak (epidemiologic parameters, severity of infection) and from the structure of the healthcare system (number of available hospital beds, testing facilities, personnel) (3–7). Economic constraints overtake biological constraints as the crisis extends, especially when the disease becomes endemic. Business resumption and diminished social welfare call into question both the cost-effectiveness of the policy and its acceptability for individuals in a compromise between the resumption of activities and public health (8–10). In addition to these standard constraints for decision-making, policymakers must address the biological uncertainty of a new virus (i.e., treatment, vaccine availability, immunity duration, relapse) and economic uncertainty (lockdown impact with large-scale shock and resilience of the social-ecological system). However, neither citizens nor policymakers like to deal with uncertainty. This situation justifies lean management that is adjustable in the short, middle and long term.

The lockdown and lockdown lift strategies differ by country, regardless of the country's sociodemographic characteristics. Up to mid-2020, the short- and middle-term strategies adopted prioritized public health outcomes while considering economic and societal (well-being) constraints. The middle- and long-term strategies will likely differ from the short-term strategies for countries that initially highlighted safety-first (strict lockdown), which may limit the economic and psychological consequences of the previous strategies, or for other countries with very light initial lockdown, which may now increase population protection and face high political risk.

A recent review highlighted the 5 key factors that have led to contractions in activity (and economy): direct losses due to death and infections, losses due to government policies such as lockdown and restrictions, declines in household consumption, local interactions within supply chains and trade, and possible hysteria effects that prevent a return to pre-crisis economic equilibrium (11). Gollier (12) noted that a limitation of many studies focused on COVID-19 lies in the way uncertainty is accounted for and the decrease in the studies' relevance with time. Macroeconomic studies focusing on international or national issues tend to assess past and/or future impacts of pandemics (13–16). They may or may not include solutions and suggestions to mitigate future impacts (17). Other economic studies focus on firms' strategies to limit the crisis impact; to date, these studies have underestimated impacts such as mental health (18). Observational or simulation-based studies based on sociology, psychology and economic approaches emphasize the efficiency of measures to change individuals' behavior and modulate outbreak dynamics (19–21).

Some bioeconomic studies deal with the trade-off between alternatives to control COVID-19, such as waiting for a vaccine, developing herd immunity, contact restrictions and, more broadly, all non-pharmaceutical interventions (22, 23). Interestingly, few bioeconomic optimization approaches that combine epidemiologic and economic approaches and accounting for multi-criteria decisions are available for COVID-19. Optimizing lockdown policies in India has been proposed using reinforcement learning (24).

A targeted lockdown lift strategy may help to achieve multiple objectives simultaneously and to find the trade-off between societal, economic, and public health criteria (2). We propose an empirical application of such an integrated bioeconomic optimization approach. With the example of the fourth largest French city, we model the lockdown lift under different scenarios and evaluate the best long-term strategies to highlight which political levers should preferentially focus on minimizing long-term impact.

MATERIALS AND METHODS

A bioeconomic model was developed to support the long-term lockdown lift strategy for Toulouse, a French city with 475,000 inhabitants. The model consists of an epidemiologic compartmental model that mimics epidemic dynamics and an economic optimization model that accounts for both monetary impact (local gross domestic product (GDP) and medical care costs) and medical staff and citizen welfare. The bio-economic approach considers both demographic and socio-professional profiles of the inhabitants and is focused on the trade-offs between economic impact limitations and the welfare of different groups of citizens.

Epidemiologic Compartmental Model

We built a deterministic discrete age-structured model, considering the demographic and age profile share of the population (younger than 18 years old, adults, and seniors) based on the work performed by Di Domenico et al. (25). The compartmental model is described in **Figure 1**. In brief, individuals are divided into susceptible, exposed, infectious, hospitalized, in intensive care units (ICUs), recovered, and deceased. A prodromic phase is considered before the appearance of symptoms. During this phase, individuals have a smaller transmission rate (Tr) with respect to symptomatic individuals. During the second step of the infectious phase, individuals may remain asymptomatic (I_a) or develop different degrees of severity of symptoms. Individuals may remain paucisymptomatic (I_{ps}) or face mild (I_{ms}) or severe (I_{ss}) symptoms. Asymptomatic individuals (including children) have a smaller transmission rate (Tr) than symptomatic individuals. Children are assumed to become either asymptomatic or paucisymptomatic only and are considered to be as susceptible as adults. The recovery stage has been divided into recovery from an epidemiologic point of view (REp), meaning staying at home after the disease, and

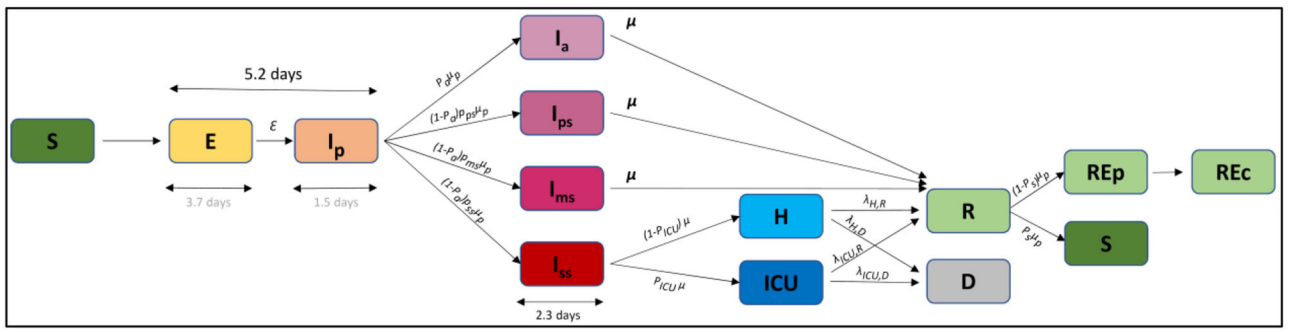

FIGURE 1 | Compartmental model. S, susceptible; E, exposed; Ip, infectious in the prodromic phase; Ia, asymptomatic infectious; Ips, paucisymptomatic infectious; Ims, symptomatic infectious with mild symptoms; Iss, symptomatic infectious with severe symptoms; ICU, severe case admitted to ICU; H, severe case admitted to the hospital but not in intensive care; Rep, recovered without economic activity; Rep, recovered with economic activity; D, deceased.

TABLE 1 | Description of the socio-professional categories and the lockdown exit scenarios.

		Young (<18 year)	Students	Unemployed	Seniors	Medical	Essentials	Active_ lower	Active_ fixed	Active_ Intermediate	Active_higher
Class of epidemiologic risk category		Child	Adult	Adult	Seniors	Adult	Adult	Adult	Adult	Adult	Adult
Inhabitants number		80,500	75,000	43,500	64,500	26,775	26,775	33,500	41,650	41,650	41,650
$ActRelease_{Popi,Lj}$	L0	3%	3%	3%	3%	100%	100%	3%	3%	3%	3%
	L1	3%	3%	3%	3%	100%	100%	50%	50%	50%	50%
	L2	3%	3%	3%	3%	100%	100%	75%	75%	75%	75%
	L3	3%	3%	3%	3%	100%	100%	100%	50%	50%	50%
	L4	3%	3%	3%	3%	100%	100%	50%	100%	100%	50%
	L5	3%	3%	3%	3%	100%	100%	50%	50%	50%	100%
	L6	100%	3%	25%	20%	100%	100%	50%	50%	50%	50%
	L7	100%	3%	25%	20%	100%	100%	75%	75%	75%	75%
	L8	100%	3%	25%	20%	100%	100%	100%	50%	50%	50%
	L9	100%	3%	25%	20%	100%	100%	50%	100%	100%	50%
	L10	100%	3%	25%	20%	100%	100%	50%	50%	50%	100%
	L11	100%	3%	25%wc	25%wc	100%	100%	40%wc	40%wc	40%wc	40%wc
	L12	100%	3%	25%wc	25%wc	100%	100%	75%hwc	75%hwc	75%hwc	75%hwc
	L13	100%	3%	25%wc	25%wc	100%	100%	75%hwc	40%wc	40%wc	40%wc
	L14	100%	3%	25%wc	25%wc	100%	100%	40%wc	75%hwc	75%hwc	40%wc
	L15	100%	3%	25%wc	25%wc	100%	100%	40%wc	40%wc	40%wc	75%hwc
	L99	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%

$ActRelease_{Popi,Lj}$ is the percentage of activity released for scenario L j and population i. For L11 to L16, wc, and hwc represent containment of contacts within categories (wc) or half containment of contacts within categories (hwc).

from an economic point of view (REc), meaning returning to work (with the same current rules at this time). After infection, a small part of the population ($P_s = 10\%$) is considered to be susceptible again.

Three main populations were considered for the epidemiologic approach (young, adults, and seniors), and the model was refined by adding the socio-professional characteristics of the adults to account for differential lockdown exit strategies on this subpopulation (**Table 1**). The categories "medical" and "essential" workers were created, representing 30% of the whole active population. Students and unemployed subpopulations were also created since their movement and contacts were expected to differ from other adult populations during the lockdown and lockdown lift (26, 27). Four other socio-professional categories were created (26) based on (i) the impossibility of having at least partial remote work (denoted *Fixed*) and a simplification of the official socio-professional classification: lower supervisory and technical occupations (denoted Lower), intermediate occupations (denoted *Intermediate*), and higher managerial, administrative, and professional occupations (denoted *Higher*). Small employers and individual entrepreneurs were not a specific category since they fall into either the fixed or the intermediary category. Similarly, lower managerial, administrative and professional occupations were not distinguished from other lower occupation profiles and were included in the Lower category.

The biological model is based on the principle that contacts within and between the subpopulations are modulated during the lockdown and thereafter depend on the lockdown lift scenarios. The likelihood of becoming *Exposed* (**Figure 1**) consequently depends on the contact matrix and the transmission rate (i.e., probability of becoming *Exposed* if in contact with an *Infectious* person). The number of simulated contacts during lockdown and for each lockdown scenario were defined in relation to the percentage or activity released, as indicated in Equation (1):

$$\text{Contacts}_{\text{Popi*Popi',Lj}} = \text{CoefContact} * \text{Contact}_{\text{Popi*Popi',Init}} * \text{ActRelease}_{\text{Popi,Lj}} \quad (1)$$

where

$\text{Contacts}_{\text{Popi*Popi',Lj}}$: contact matrix for the scenario L *j* and the populations *i* and *i*'

CoefContact: ponderation of the initial contact matrix due to change in behavior with time

$\text{Contact}_{\text{Popi*Popi',Init}}$: initial contact matrix for the populations *i* and *i*'

$\text{ActRelease}_{\text{Popi,Lj}}$: percentage of activity released for scenario L*j* and population *i*.

Lockdown and Lockdown Lift Scenarios

In the lockdown scenario (L0, **Table 1**), all subpopulations are locked (3% of released activity in terms of contacts) except medical and essential workers. This represents the policy implemented in France in phase 1, from March 18th to May 11th, 2020 (28). Schools were closed, and 70% of non-essential workers worked remotely.

In phase 2, starting May 11th, three sets of monitored lockdown lift strategies (L1-L5, L5-L10, and L11-15) were simulated (**Table 1**) and applied. For all scenarios, medical, and essential workers remained unlocked. In scenarios L1 to L5, all non-active subpopulations remained locked, and the 4 populations with economic activities experienced partial or total lockdown lift. Scenarios L6 to L10 were defined similarly to L1 to L5 with all schools open and partial unlocking of unemployed and seniors. L11 to L15 represent the same situation as L6 to L10 with containment of contacts within categories (*wc*) or partial (half) containment of contacts within categories (*hwc*). This means that lockdown lift is adjusted to allow activities for specific days of the week depending on the subpopulation, leading to strictly limited inter-sub-population contacts. A mixed strategy was adopted with half within category contacts, limiting half of the contact between subpopulations thanks to a population-week regulation system (precise rules defining the combinations of exit authorizations depending on socio-professional category). In addition to the monitored scenarios L0-L15, a total lockdown exit at the start of phase 2 (scenario L99) was considered.

To better match the observed measures in the field, the monitored lockdown lift of phase 2 was combined with various options. The lockdown lift was implemented abruptly on May 11th (O1) or progressively at 4 or 8 weeks (O2 and O3). Because scenarios L1 to L15 cannot be applied indefinitely due to their economic and societal impacts, a third phase was created, and 2 other options were defined (based on O3 rules) to capture the long-term dynamics. Option O34 planned a total lockdown 2 weeks after the end of hospital saturation or after the peak of hospitalization if no saturation occurred. The total lockdown exit was definitive for O34 and was transitory for O35 (mixed strategy of lockdown lift and re-lockdown). The starting date of phase 3 consequently depends on the lockdown lift scenario.

Figure 2 summarizes the 3 phases of the French situation and the corresponding simulated lockdown exit strategies.

Economic Optimization Model

Six economic scenarios (denoted E0 to E5) were considered (**Table 2**) for the 4 studied active populations locked down (Active_fixed, Active_lower, Active_intermediate, and Active_higher). During lockdown, the percentage of productivity compared to the pre-lockdown period is considered to vary depending on the socio-professional category (E0). This decrease in productivity is an average for the whole lockdown period (phase 1) and the subpopulation and should not be compared to productivity of workers with partial home working before lockdown. During the monitored lockdown lift (phase 2), the percentage of productivity compared to the pre-lockdown period was considered to depend on the percentage of activity released, in accordance with the lockdown lift scenario for a given subpopulation, as indicated in Equation (2):

$$\text{Prod}_{\text{Popi,Ek}} = \begin{cases} 100 * \text{ActEco}_{\text{Popi,Ek}} * \text{GDP}_{\text{Popi,Pl}}, \\ \quad if\ k = 0 \\ \left[\text{ActEco}_{\text{Popi,E0}} + \left(100 - \text{ActEco}_{\text{Popi,E0}}\right)\right. \\ \left.\text{ActEco}_{\text{Popi,Ek}};\ \text{Max}\ 100\right] * \text{GDP}_{\text{Popi}},\ if\ k > 0 \end{cases} \quad (2)$$

where:

$\text{Prod}_{\text{Popi,Ek}}$ is the productivity permitted by the active population Pop *i* (Active_fixed, Active_lower, Active_intermediate, and Active_higher) for the economic scenario E*k* and the lockdown lift scenario L*l*

$\text{ActEco}_{\text{Popi,Ek}}$ is the percentage of economic activity for the economic scenario E*k*

GDP_{Popi} is the daily GDP for the population Pop*i*.

Equation (2) aims to reproduce the fact that partial lockdown may help to improve economic activity compared to strict lockdown and that very good performance can be achieved with partial lockdown for some socio-professional categories.

Optimization under constraint was performed on the minimal total cost for Cost E_k, L_j, and hospitalization for the whole 300 or 600 d period. Economic risk was not accounted for. To combine the main key dimensions within the decision-making, the optimal solution that minimizes the overall economic impact for a given Tr was plotted considering 3 main constraints. Three levels of constraint were considered based on the quartile and median mortality rate observed between all the scenarios for a given option and a given Tr. The mortality criteria high, medium and low used for optimization correspond to no constraints on mortality, within the best half of the situation (lowest half mortality rate) and within the best quarter (lowest quartile mortality rate), respectively. The same type of rule was applied for the welfare criteria. The welfare criteria high, medium and

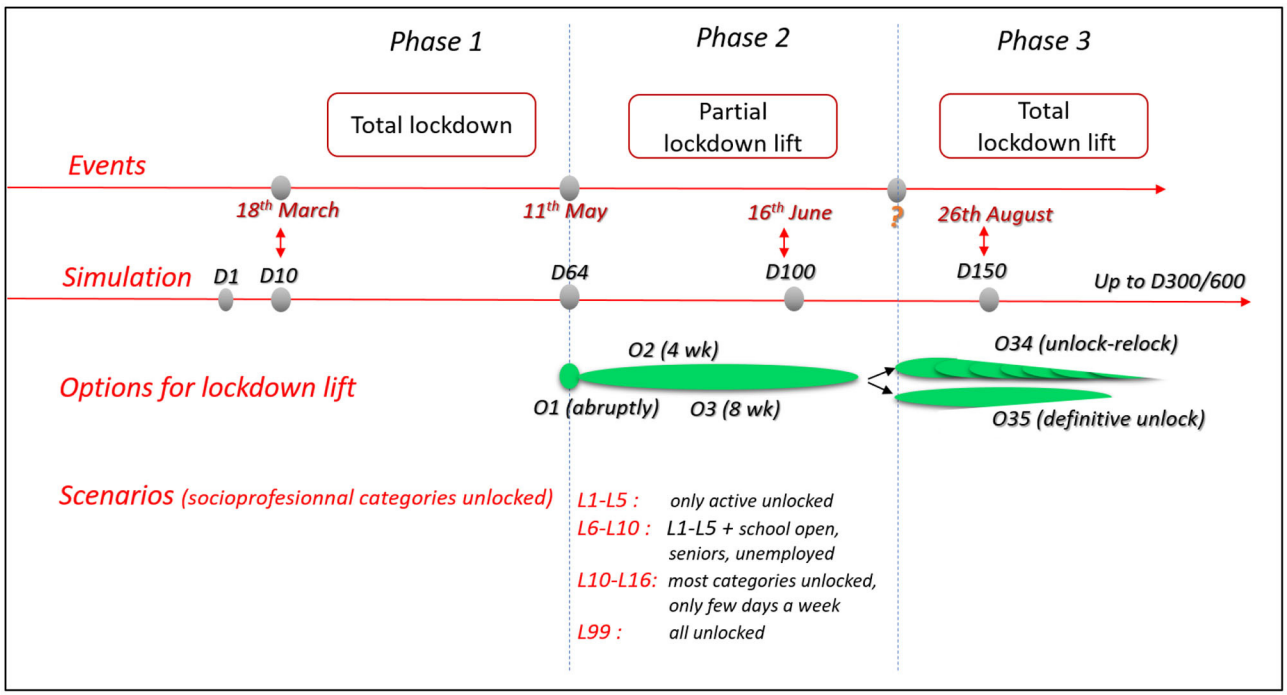

FIGURE 2 | Flowchart of observed events and simulated options and scenarios for the 3 phases of the COVID-19 outbreak in the studied area.

TABLE 2 | Economic scenarios and global production for the 4 active populations.

	Active_lower	Active_fixed	Active_ Intermediate	Active_higher
ECONOMIC SCENARIO $ActEco_{Popi,Ek}$				
E0	25%	0%	66%	66%
E1	$ActRelease_{Popi,Lj}$			
E2	$ActRelease_{Popi,Lj}$		$ActRelease_{Popi,Lj}$ + 25%	$ActRelease_{Popi,Lj}$
E3	$ActRelease_{Popi,Lj}$			$ActRelease_{Popi,Lj}$ + 25%
E4	$ActRelease_{Popi,Lj}$ + 15%			
E5	$ActRelease_{Popi,Lj}$ − 5%			
INDIVIDUAL GLOBAL PRODUCTION GDP_{Popi} (€ PER DAY)				
	326	326	423	571

low used for optimization correspond to within the best half or 75% of the number of person-days unlocked or no constraints on person-days unlocked, respectively. The criteria related to hospital saturation were defined by the duration of hospital saturation not to exceed or to the number of day-beds lacking for the whole period, with the criteria high meaning no constraints. The calculation of the total cost for each scenario and option allowed us to calculate the opportunity cost of choosing any combination of scenario and option compared to the scenario and option with the minimal cost for the whole period and given Tr.

Model Parameterization

The number of contacts per person was defined within and between the 8 subpopulations, meaning *de facto* that contacts within and between the 3 epidemiologic populations (young, adults, and seniors) were considered. Hospitalization and admission to the ICU for severe cases were identified from Toulouse hospital data (29) and adjusted for the analyzed population. Hospitalization and ICU bed occupations were used to evaluate the capacity to welcome patients requiring these levels of care. The calibration of the compartmental model (**Table 3**) was performed similarly to Di Domenico et al. (25). At the beginning of the lockdown, other French areas were close to the hospital saturation level, and communication by the media raised peoples' awareness of health risks. We consequently consider that people changed their behavior dramatically for both the number of contacts during lockdown and Tr. As a consequence, the number of contacts within and between the subpopulations (**Table 4**) was based on previous publications (25, 30) and adjusted for the number of hospitalized and ICU patients during lockdown for the considered area. The simulated incidence of clinical cases was compared with the observed local incidence to appropriately adjust the number of contacts (**Table 4**). The value of Tr was likely to change with time during the studied period due to changes in rules, behaviors and protections availability, including masks. It was kept constant for a given simulation, and the values of 0.06, 0.10, 0.125, 0.20, and 0.25 were retained.

The assumptions on social distancing intervention made by (25) were kept. A 75% decrease in the number of contacts is expected if severe symptoms are observed in one individual.

TABLE 3 | Parameters, values, and sources to define the bioeconomic model.

	Young	Students	Un-employed	Senior	Medical	Essentials	Active_ lower	Active_ fixed	Active_ Intermediate	Active_ higher
Young	12.00	1.44	3.12	1.20	1.08	1.08	3.60	3.12	2.40	1.20
Students	4.32	3.36	2.64	1.68	0.45	0.69	2.04	2.64	2.64	2.52
Unemployed	4.32	3.36	2.64	1.68	0.66	0.45	2.04	2.64	2.64	2.64
Senior	0.30	0.60	3.12	8.40	0.42	0.42	2.40	2.40	1.68	0.12
Medical	4.32	3.36	2.64	1.68	0.66	0.45	2.04	2.64	2.64	2.64
Essentials	4.32	3.36	2.64	1.68	0.45	0.69	2.04	2.64	2.64	2.52
Active_lower	3.60	2.40	3.60	2.40	0.51	0.51	2.88	2.52	2.52	2.40
Active_fixed	3.12	2.4	4.44	2.40	0.66	0.66	2.52	4.56	1.20	0.48
Active_Intermediate	2.40	2.4	0.84	1.68	0.66	0.66	2.52	1.20	6.00	4.08
Active_higher	1.20	4.44	0.12	0.12	0.66	0.63	2.40	0.48	4.08	8.40

TABLE 4 | Matrix contact (value of $Contact_{Popi*Popi',Init}$) for the different populations.

Variable	Description	Value	Source
Θ^{-1}	Incubation period	5.2 d	1
μ_p^{-1}	Duration of prodromal phase	1.5 d, computed as the fraction of pre-symptomatic transmission events out of pre-symptomatic plus symptomatic transmission events	2
ϵ^{-1}	Latency period	Θ^{-1} - μ_p^{-1}	–
p_a	Probability of being asymptomatic	0.2, 05	3
p_{ps}	If symptomatic, probability of being paucisymptomatic	1 for children 0.2 for adults, seniors	4
p_{ms}	If symptomatic, probability of developing mild symptoms	0 for children 0.7 for adults 0.6 for seniors	4
p_{ss}	If symptomatic, probability of developing severe symptoms	0 for children 0.1 for adults 0.2 for seniors	4–6
s	Serial interval	7.5 d	7
μ^{-1}	Infectious period for I_a, I_{ps}, I_{ms}, I_{ss}	S - Θ^{-1}	–
r_β	Relative infectiousness of I_p, I_a, I_{ps}	0.51	8
p_{ICU}	If severe symptoms, probability of going in ICU	0 for children 0.36 for adults 0.2 for seniors	9
$\lambda_{H,R}$	If hospitalized, daily rate entering in R	0 for children 0.072 for adults 0.022 for seniors	9
$\lambda_{H,D}$	If hospitalized, daily rate in D	0 for children 0.0042 for adults 0.014 for seniors	9
$\lambda_{ICU,R}$	If in ICU, daily rate entering in R	0 for children 0.05 for adults 0.036 for seniors	9
$\lambda_{ICU,D}$	If in ICU, daily rate entering in D	0 for children 0.0074 for adults 0.029 for seniors	9

Five percent of adults stayed at home in the case of school closures, with the exception of the medical and essential activities subpopulations. Working from home was adopted by 6% of the active adult population before the lockdown. The isolation of positive cases when returning home was not considered as possible for phase 1, in accordance with the main observations during this phase. The number of beds available for hospitalization and ICU was 1,000 and 300, respectively (29). A higher number of patients hospitalized or in the ICU on a given day defined the saturation situation, which was associated with a three-fold higher mortality risk for people above the threshold. The price per day-bed was fixed to 500 € and 1,500 € for hospitalization and ICU, respectively (31).

The parameters of the six economic scenarios are reported in **Table 2**. The range of activity during lockdown compared to the pre-lockdown period was considered to vary between 0 (fixed) and 66%. This means, for instance, that the productivity of a home worker is 66% of his or her former productivity. A sensitivity analysis is permitted with scenarios E2 to E4, which attribute a fixed extra percentage of productivity, and in scenario E5 (limited productivity even if there is a high rate of lockdown lift).

Daily GDP was obtained as the yearly GDP per worker [€77,212 in 2018 for the Occitanie area (32)] and adjusted for each subpopulation due to variation in the official estimation of socioprofessional standard living incomes (27). The local standard living incomes were officially assessed as €18,870, €18,870, €24,520, and €33,090 for the socio-professional categories Active_low, Active_fixed, Active_intermediate, and Active_high, respectively. The yearly GDP per worker for each socio-professional category was then divided by 200 days worked yearly (**Table 2**).

We calibrated our model with demographic and socioeconomic data describing Toulouse area i.e., a French metropoly with a relatively high level of economic activity and several universities and higher education structures. Our findings may not be extrapolated to other cities, as the

parameters may vary between cities. However, many of the cities with similar sizes in Europe would likely have close levels of healthcare and university facilities. To some extent, our results provide valuable information for scientists and policy-makers beyond Toulouse area. At least we laid down in this empirical application the rationale and the elements required to implement a tailored and adaptive approach of COVID-19 management.

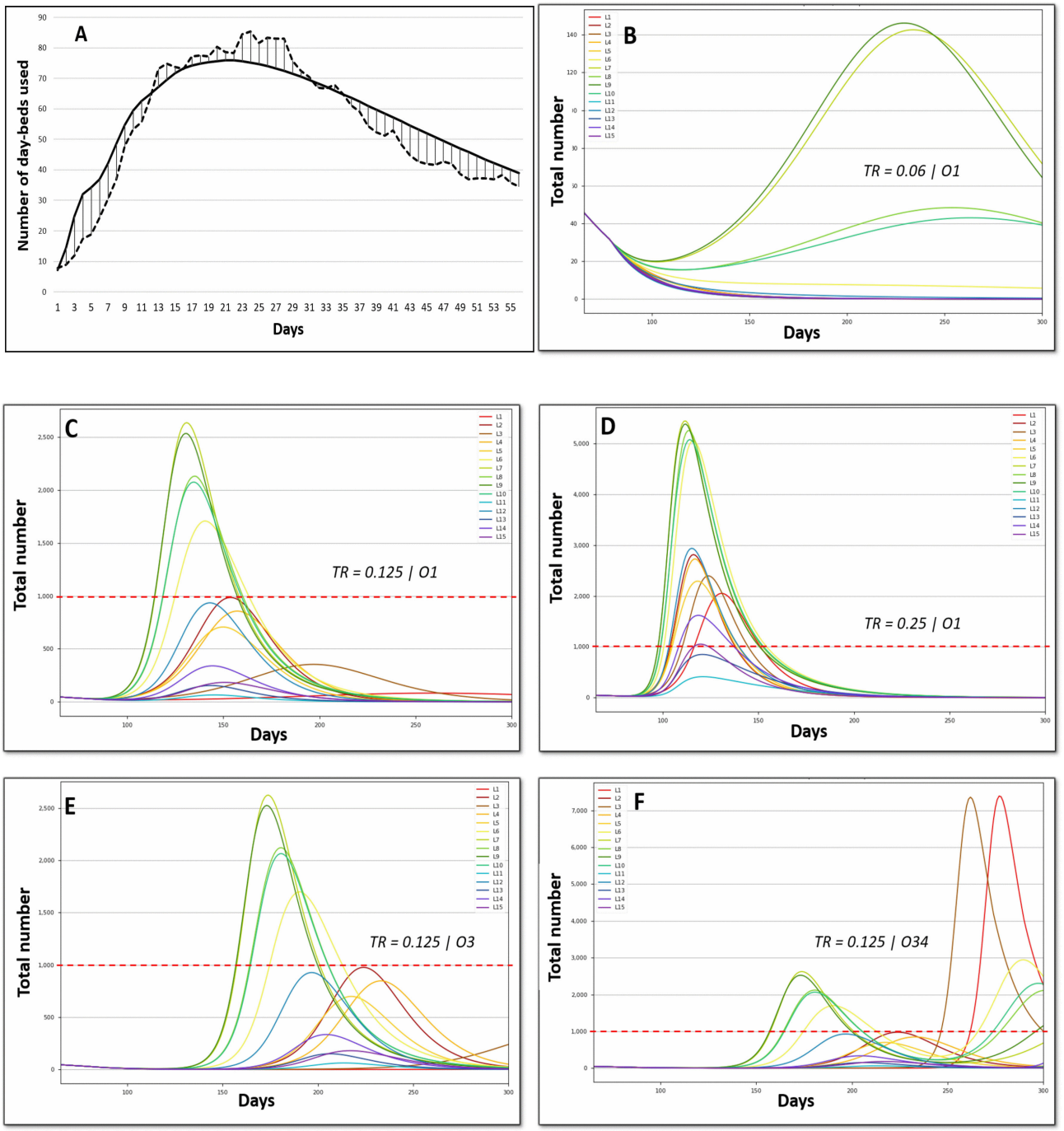

FIGURE 3 | Epidemiologic validation of the model. **(A)** Comparison between the predicted (solid line) and observed (dashed line) number of day-beds used. **(B–F)** Number of daily beds used in hospital (CIU excluded). The red dashed line represents the hospital capacity. Tr, transmission rate; Option 1, abrupt monitored lockdown lift early in phase 2; Option 3, progressive monitored lockdown lift on 8 weeks; Option O34, progressive total lockdown lift (phase 3).

RESULTS

The results are presented for a 300- and 600-day period simulation to represent the short- and mid-term impacts. The lockdown starts on day 10 of the simulation (18th March 2020), and the lockdown lift starts on day 64 (11th May 2020). Day 100 corresponds to mid-June 2020, and day 150 corresponds to late August 2020 (**Figure 2**).

Validation and Sensitivity of the Bioeconomic Model

The validation of the epidemiological part of the model was based on the comparison between the simulated and observed number

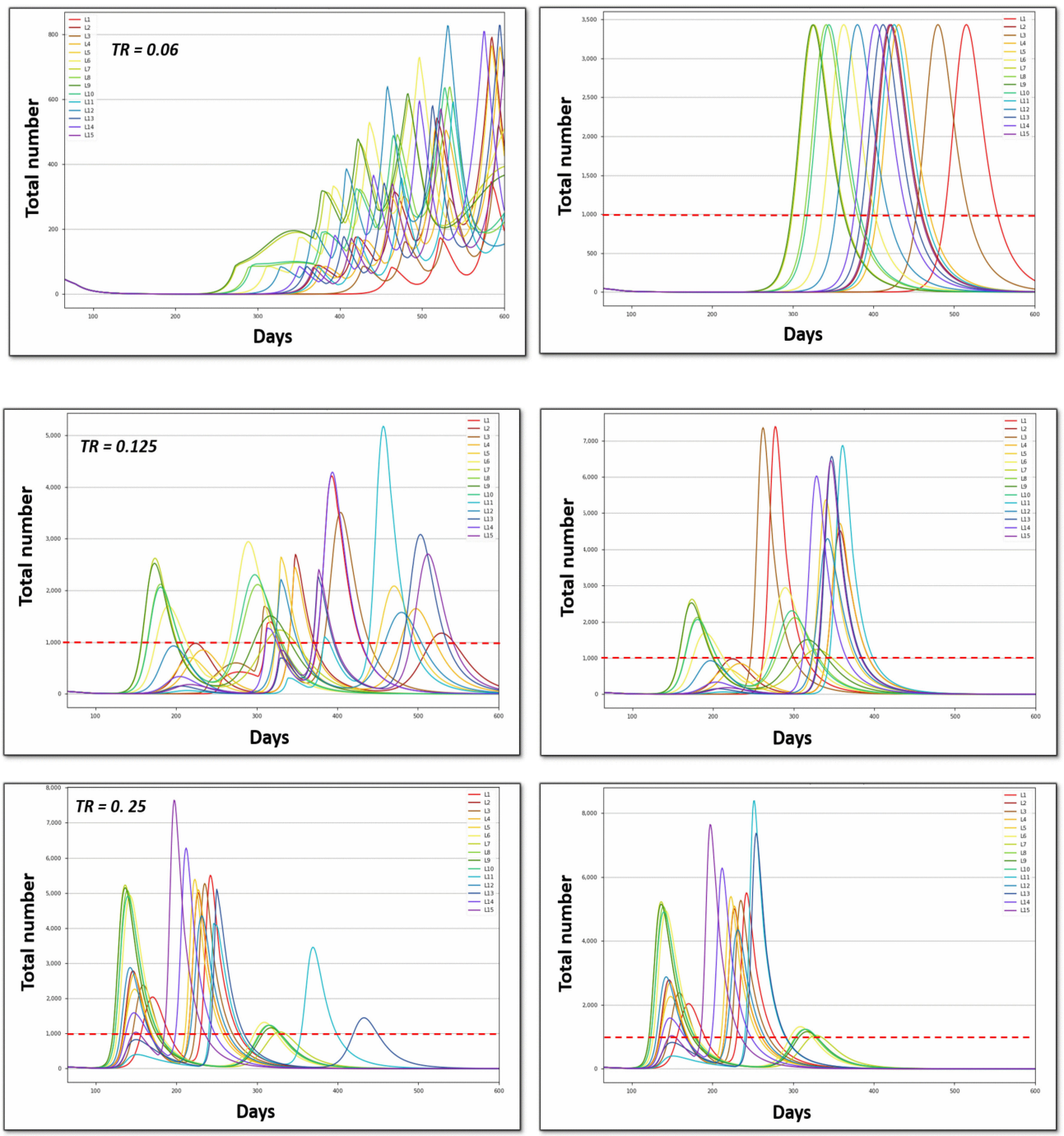

FIGURE 4 | Number of daily beds used in the hospital (ICU excluded) for the different scenarios (L1 to L15). Tr, transmission rate; the red dashed line represents the hospital capacity. Option O34 (left), progressive total lockdown lift (phase 3); Option O34 (right), abrupt total lockdown lift (phase 3).

of day-beds used, with a high match observed (**Figure 3A**). The results were highly sensitive to Tr, as illustrated for option O1 in **Figures 3B–D**: the number of day-beds used was very low for a Tr of 0.06 and increased dramatically when Tr increased to 0.125 and 0.25. Because the change in Tr represents the average population behavior around virus transmission in our model, the results are presented for these 3 values of Tr. The results also highlight the capability of the scenarios to represent various situations in terms of outbreak dynamics for the different phases (**Figures 3B–D**). For instance, hospital saturation may be prevented by some combination of Tr and scenarios, whereas other combinations lead to long and intense hospital saturation.

For a given Tr (**Figures 3C,E** for Tr = 0.125), extending the lockdown lift by 8 weeks, as occurred in France for most activities, postponed the peak (to a greater degree when the peak was low) but failed to reduce the peak intensity. The adoption of a total lockdown leads to a second wave. For a lockdown simulated at 8 weeks and Tr = 0.125 (**Figure 3F**, O34), the second wave starts on day 250. This clearly shows the need for long-term consideration to improve multi-criteria decisions.

Options O34 and O35 were consequently modeled up to 600 days (**Figure 4**). On the one hand, the greater the Tr (top to down for a given column), the earlier and the higher the peak for both the strategy of lockdown lift and re-lockdown (O34, left) or the total definitive lockdown strategy (O35, right). Hospital saturation was only avoided when Tr remained very low (Tr = 0.06) and with lockdown lift and re-lockdown strategies (O34). These results demonstrate that individual behavior (i.e., the Tr value) is more important than political strategy (scenario choices) for the long-term overall impact. On the other hand, for a given Tr (i.e., given an average behavior), scenario choices permitted the management of the hospital saturation level, including intensity and duration.

Multidimensional Long-Term Optimization

The optimal solutions under different levels of constraints are reported in **Figures 5**, **6**, **Supplementary Figures 1**, **2**. The solution that minimizes the overall economic impact is located in the foreground of **Figures 5**, **6**, **Supplementary Figures 1**, **2** (high welfare, low mortality and low saturation). The results indicate the name of the scenario and option as well as the corresponding direct total cost compared to the reference (opportunity cost value = 0). The total cost of lockdown strategies for O34 and the 300-day period was €2.15 billion for L99 and varied from €3 to €6 billion for scenarios L1-L15.

Short-term optimization (**Figure 5**) shows that improving one criterion necessarily leads to deterioration of another criterion. Combining L4 or L14 and O3 represents the best strategy in most of the situation for low Tr, with an opportunity cost of €1.29–€1.88 billion for the 300 d period. For higher Tr, options O1, O3, and O34 and scenarios L3, L4, L5, L12, L13, and L14 appear to be optimal providing that constraints are released on at least 2 criteria. The direct cost of optimal scenarios to improve welfare or to decrease mortality and hospital saturation vary between €1.2 and €2.7 billion (L99 excluded).

Considering the long-term impact (**Figure 6**) leads to dramatically different results, with Option O34 as the best solution except for very few situations. The lockdown lift and re-lockdown strategies fulfill the 3 constraint criteria for at least Tr = 0.06 and 0.125. For Tr = 0.25, neither welfare nor saturation constraints may be completed. The best scenarios for long-term optimization are L4 for Tr=0.06 (similar to short-term analysis), L4 and L13 for TR = 0.25 and L2, L4, L7, L9, and L12 for TR = 0.125. The opportunity cost is €1.28 billion for Tr = 0.06, €0.68–€1.44 billion for Tr = 0.125 and €0.51–€2.42 billion for Tr = 0.25. Very similar results are observed when formulating the saturation constraints in terms of saturation duration without the condition of saturation intensity (**Supplementary Figure 1**) instead of per patient-saturated numbers (**Figure 6**).

The second or third best optimal strategy (**Supplementary Figure 2**) is consistently found to be option O34 combined with scenarios L2, L3, L4, L5, L7, L8, L9, and L12. The opportunity cost compared to the first best solutions for each set of constraints is small to very small, showing little difference linked to the choice of the scenario within this range of scenarios.

DISCUSSION

The present work is the first long-term bioeconomic multicriteria optimization approach applied to COVID-19 at a local scale and was conceived to support decision-making regarding public health policy. Various criteria were considered within the economic part of the model, and the epidemiologic complexity of the situation was simplified. The present approach allows us to consider 8 socio-professional categories and 3 epidemiologic populations at a glance.

Unlike other studies, the present work focuses on a population with very limited virus circulation before lockdown. The situation in Paris and Eastern France in February and March 2020 as well as the situations in other places in Europe or worldwide clearly highlight the medical consequences of the virus, spontaneously leading to a moderate to high level of barrier routines in daily activities for both professional and non-professionals. The contact matrices and the contamination probability were adjusted accordingly in the present simulation. Because lockdown froze all professional and private activities of the majority of the population, the simplified version of the SIR modeling provided here was precise enough to predict the number of cases observed in hospitals. The value of Tr to be retained within the bioeconomic model is a key point, and all the results demonstrate that identification of the best solution is highly sensitive to this parameter. It represents individual behaviors related to barrier gestures and individuals' compliance with biosecurity and social distancing rules. Its true value is consequently very difficult to appraise and may even change between socio-professional categories (e.g., education, information asymmetry). The fixed Tr value for a given set of scenarios and options is an important simplification of the present study since Tr is likely to change over time. The options offered to people to protect themselves (disinfectant gel, masks, etc.) and the rules or recommendations provided by authorities may influence the value of Tr. For instance, in France, masks

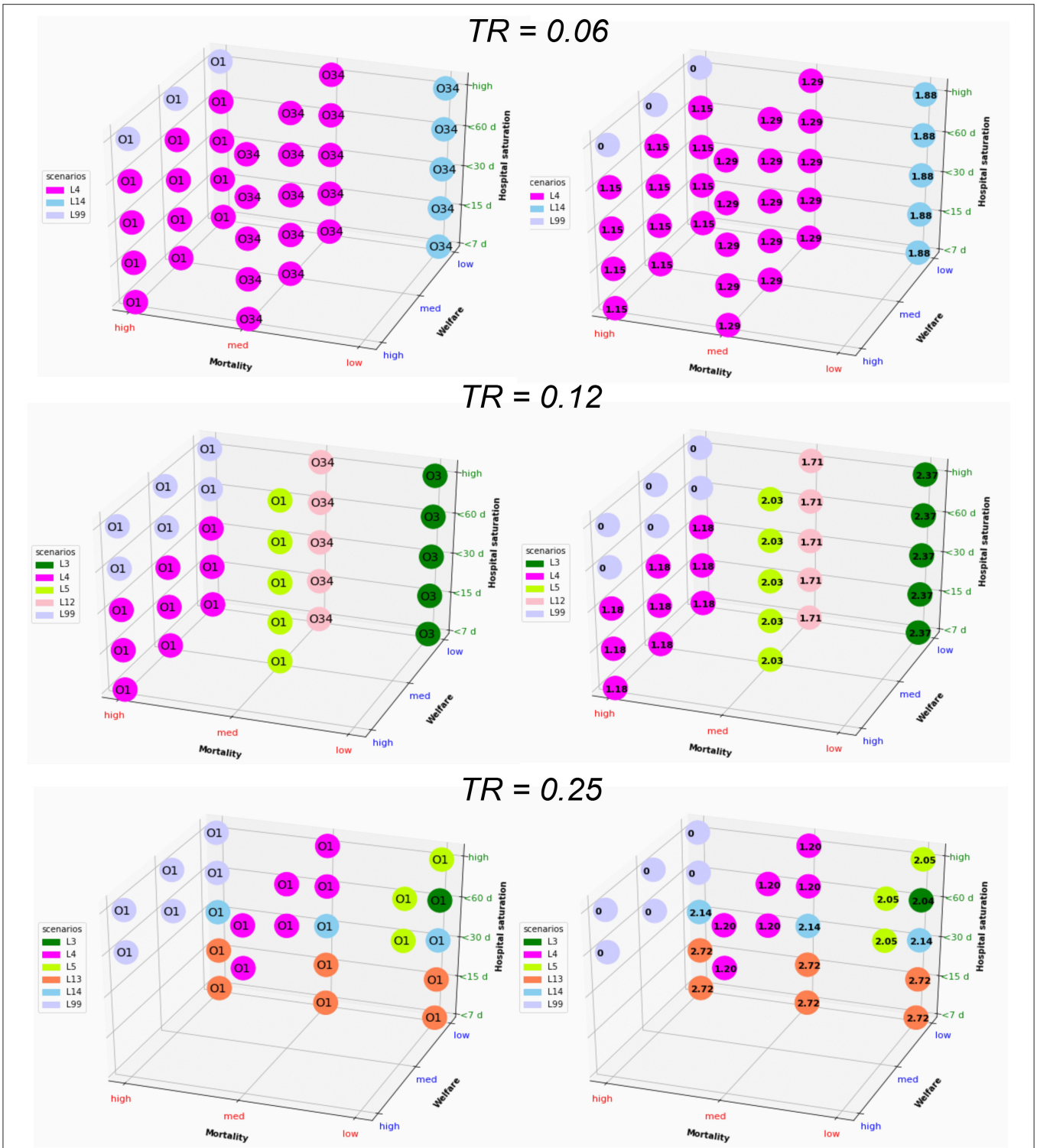

FIGURE 5 | Graphical representation of the optimal solution depending on the strength of the constraint for a whole period of 300 days. The results in the right column are expressed as direct cost (in billion euros); Tr, transmission rate. The optimal solution that minimizes the overall economic impact under a set of constraints is found in the foreground (low mortality, high welfare, and low saturation).

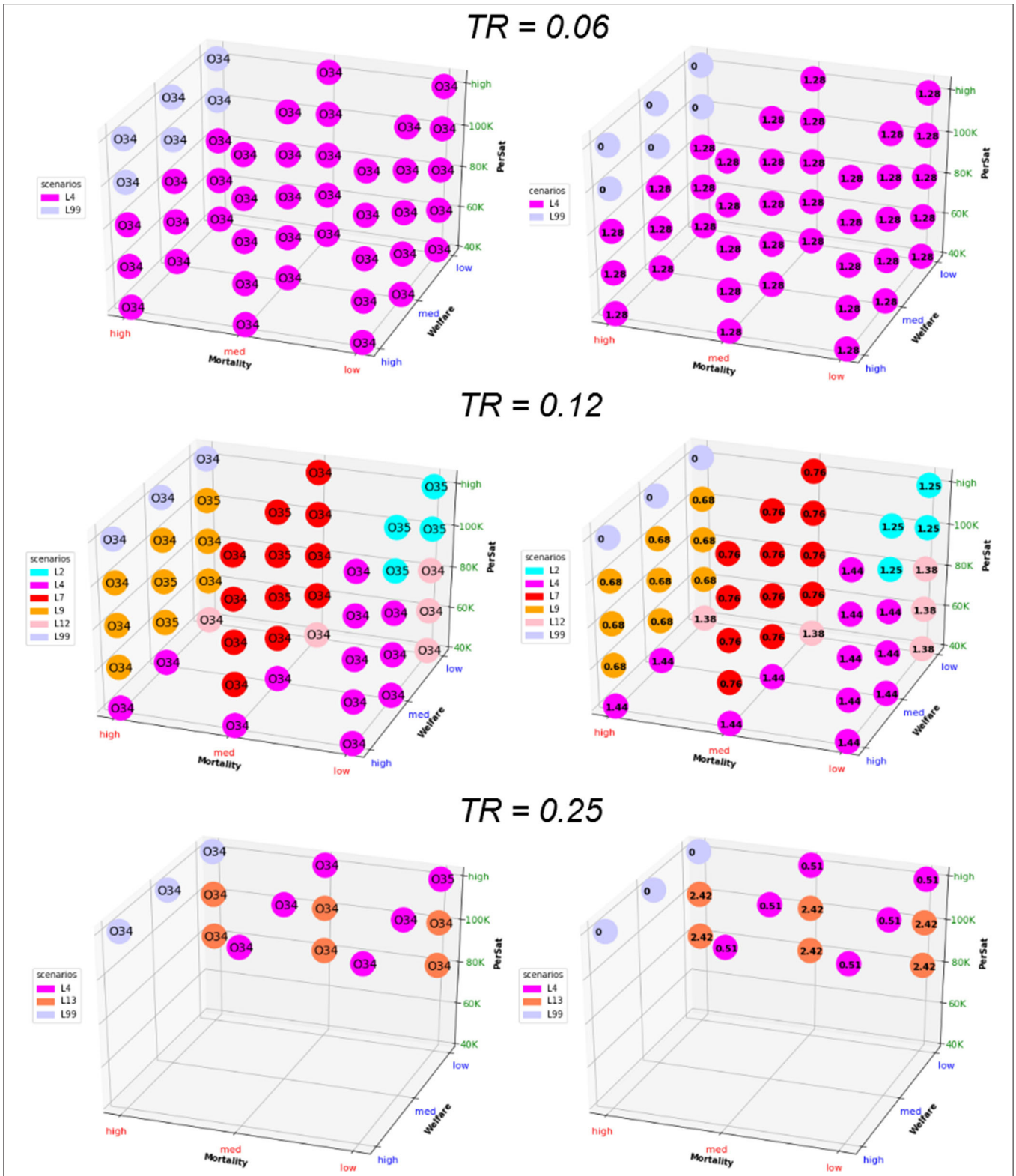

FIGURE 6 | Graphical representation of the optimal solution depending on the strength of the constraint for a whole period of 600 days. The results in the right column are expressed as direct cost (in billion euros); Tr, transmission rate. The optimal solution that minimizes the overall economic impact under a set of constraints is found in the foreground (low mortality, high welfare, and low saturation).

were available for everyone at the beginning of phase 2, and the recommendation of mask wearing has changed over time (first on a voluntary basis and in mid-summer, mandatory in all closed public rooms and outside in some crowded tourist towns). Moreover, the sensitivity of people was limited when prevalence was low in France and Europe but then increased during summer 2020, when the second wave was observed in other European countries and movement bans reappeared.

The progressive lockdown lift, as simulated for 8 weeks in option O3, is very close to the field situation. When phase 2 started, the practical application of the lockdown lift took 1–2 months as many offices, schools and day cares were not in a situation to host people. High schools and universities remained closed up to September 2020. Most social activities (museums, restaurants, pubs and cinemas) opened progressively from May to August 2020. Traveling was first authorized within 100 km of home, and then free circulation was authorized. The ability of the present model to closely represent the lockdown lift strategy can be considered high. A limitation of our model is that it does not account for summer breaks and the higher rate of movement and contact that may take place during this specific period.

The present work used a simplified vision of economic dynamics by summarizing the creation of value by each actor to his or her daily contribution to the GDP before lockdown. A global and dynamic approach of the industrial and economic activities that could be permitted by economic global (or partial) equilibrium modeling or the equivalent may provide a precise approach to guide decision making. It may help to better consider the interrelationship between sectors and the dependency between actors and post-disaster recovery dynamics. It is difficult to truly appreciate the relationship between the sectors and all the information required to parametrize the models during the recovery phase due to the paucity of updated information. This means that most of the calibration would be based on an assumption of business as usual. Using GDP per socio-professional category is a strong assumption, and GDP is clearly a very raw proxy of the state of the economy. However, it allows the combination of SIR outbreak modeling and economic societal considerations within a unique decision-making process, which clearly adds value compared to previous studies.

The main results of the present work are that policy makers should focus more on individual behaviors (represented by the Tr value) than on trying to optimize lockdown strategy (defining who is unlocked and who is locked). Social distancing is recognized as a key parameter to limit the spread of diseases but is often associated with high economic impact (17). The main challenge is therefore to maintain social distancing by appropriate individual behaviors without excessive coercive government-enforced social distancing, which is very often associated with high economic impact. In countries with poor socioeconomic conditions, stringent social distancing measures and generous income support programmes have been shown to lower cases and deaths (33). These findings suggest that evaluating the global impact of COVID-19 or optimization to define the best strategy may represent a priority and that research in compartmental economics or experimental economics may be needed to address COVID-19 issues. A better understanding of individual behavioral motivations and the identification of ways to improve biosecurity compliance for everyone should become the short-term priority.

The results clearly show that no major differences in the economic impact or in the 3 criteria retained can be seen between the scenarios. Scenarios L4 and L13 appear to be the best, and scenarios L2, L3, L5, L7, L14, and L12 can also be considered as multi-criteria equivalents. The L1, L6 L10, L11, L15, or L15 scenarios should not be recommended. The scenarios that limit interactions between socio-professional categories, which can be seen as precision lockdown lift scenarios (L11 to L15), were expected to represent the best trade-off between the constraints, but they failed to ensure satisfactory welfare criteria, with the overall outdoor access limited compared to other scenarios.

In all the potentially recommended scenarios, the hospital saturation level was handled with regard to both intensity and duration. Although we demonstrate here that several criteria may be considered simultaneously for decision-making and that hospital saturation and the associated mortality increased risk cannot justify an endless strict lockdown, public health remains the most important criterion in the short term, and the scenarios contribute to its optimization. Hospital saturation is not only a public health issue but also a key political risk of lockdown policy rejection (2).

In conclusion, our results demonstrate that policy makers should focus on individuals' behavioral changes rather than on trying to optimize lockdown strategies (defining who is unlocked and who is locked). The results highlight the need for compartmental or experimental economics to address COVID-19 issues through a better understanding of individual behavioral motivations and the identification of ways to improve biosecurity compliance.

DATA AVAILABILITY STATEMENT

Publicly available datasets were analyzed in this study. This data can be found at: https://www.data.gouv.fr/fr/datasets/?q=covid&page=1.

AUTHOR CONTRIBUTIONS

AF, GL, and DR designed the study. AF and DR performed the modeling (model calibration, and Python and Gams code). AF and RB performed the simulations. AF, RB, GL, and DR analyzed the results. GL and DR wrote the manuscript. All authors contributed to the article and approved the submitted version.

SUPPLEMENTARY MATERIAL

The Supplementary Material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/fpubh.2020.606371/full#supplementary-material

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STUDY PROTOCOL
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COVID-19: Technology, Social Connections, Loneliness, and Leisure Activities: An International Study Protocol

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Drawn from the stress process model, the pandemic has imposed substantial stress to individual economic and mental well-being and has brought unprecedented disruptions to social life. In light of social distancing measures, and in particular physical distancing because of lockdown policies, the use of digital technologies has been regarded as the alternative to maintain economic and social activities. This paper aims to describe the design and implementation of an online survey created as an urgent, international response to the COVID-19 pandemic. The online survey described here responds to the need of understanding the effects of the pandemic on social interactions/relations and to provide findings on the extent to which digital technology is being utilized by citizens across different communities and countries around the world. It also aims to analyze the association of use of digital technologies with psychological well-being and levels of loneliness. The data will be based on the ongoing survey (comprised of several existing and validated instruments on digital use, psychological well-being and loneliness), open for 3 months after roll out (ends September) across 11 countries (Austria, France, Germany, India, Malta, Portugal, Romania, Spain, Turkey, and UK). Participants include residents aged 18 years and older in the countries and snowball sampling is employed via social media platforms. We anticipate that the findings of the survey will provide useful and much needed information on the prevalence of use and intensities of digital technologies among different age groups, gender, socioeconomic groups in a comparative perspective. Moreover, we expect that the future analysis of the data

collected will show that different types of digital technologies and intensities of use are associated with psychological well-being and loneliness. To conclude, these findings from the study are expected to bring in our understanding the role of digital technologies in affecting individual social and emotional connections during a crisis.

Keywords: gerontology, pandemic (COVID-19), international rapid response, quantitative data, social media, gerontechnology, social science research

INTRODUCTION

The ongoing COVID-19 pandemic, is one of the worst pandemics in human history and in the last 100 years, on a global scale and has resulted in ∼21,294,845 (267,291—in the last 24 h) infected cases, and 761,799 deaths (5,985—in the last 24 h) (World Health Organization, 2020) with the statistics still on the rise. The pandemic has caused disruptions across the usual social and economic activities. Reducing physical contact, social gatherings and the complete lockdown have indirectly redefined the common practice of work, caregiving, support and social interaction.

To date, there is a growing body of scholarly research relating to the impact of COVID-19 and citizens across different countries and continents. This includes Ammar et al. (2020a,b,c) who deployed an online survey in seven languages to understand how this pandemic was impacting on the daily living and lives of citizens in relation to social distancing, isolation and home confinement. Furthermore, Bentlage et al. (2020) and Chtourou et al. (2020) who are members of the same project have explored and provided practical recommendations for maintaining an active lifestyle and physical activity during the pandemic. Such recommendations include exergaming, yoga, and home-based exercise, with appropriate amounts of intensity conducted for both adults and children.

Scholarly research surrounding the use, benefits and impacts of digital technology in the lives of older citizens, as well as those of younger citizens (Ito et al., 2010; Cotten et al., 2014; Marston, 2019) has been growing over the last 30+ years (Czaja and Barr, 1989). The application of digital technologies in influencing social and psychological well-being have been widely studied with the focus of the types of digital connections and the intensities of using digital technologies among general population (Rosenfeld and Thomas, 2012; Hofstra et al., 2017; Verduyn et al., 2017; Rafalow, 2018; Henwood and Marent, 2019; Shah et al., 2019). The demographic profiles of the users, such as age, gender and education are important factors to understand the accessibility, frequencies and types of digital use in creating and enhancing social connections and support.

When focusing on social isolation, loneliness and the digital divide, there is a myriad of scholarly research surrounding older adults and includes exploring older adults' attitudes toward technology adoption and use (Mitzner et al., 2010; Marston, 2012; O'brien et al., 2012; Fernández-Ardèvol and Ivan, 2015; Marston et al., 2016, 2019; Rosales and Fernández-Ardèvol, 2016a,b; Fernández-Ardèvol et al., 2017; Rosales et al., 2018; Fernández-Ardèvol, 2020), leisure activities (Genoe et al., 2018), supporting independence, social support and connectedness while reducing loneliness (Bouma et al., 2004; Cotten et al., 2013; Czaja et al., 2018; Schlomann et al., 2020), the digital divide and inequalities (Cotten et al., 2009; Gilleard et al., 2015; Lagacé et al., 2015; Friemel, 2016; Hargittai and Dobransky, 2017; Ball et al., 2019; Fernández-Ardèvol, 2019), telemedicine and emerging technologies for healthcare (Sixsmith and Sixsmith, 2000; Mitzner et al., 2012; Czaja et al., 2013; Sharit et al., 2019), and to support age-in-place (Mynatt et al., 2000, 2004; Beer et al., 2012; Marston and van Hoof, 2019; White et al., 2020).

Based on the growing literature highlighted above and in the next section, coupled with the rise of digital technologies in terms of social networking sites, virtual conferencing, etc. there is alternative thoughts and approaches to maintaining social connections and activities during the crisis. In general, this growth in scholarly research illustrates a fast-moving arena within the fields of sociology, general social sciences, computer science and gerontechnology. In addition to a series of national and international research projects focusing on the various impacts and roles that technology can play within society (Ivan et al., Accepted; Ivan and Hebblethwaite, 2016; Loos et al., 2018, 2019; Marston et al., 2019; Nimrod, 2019; Nimrod and Ivan, 2019; Gallistl and Nimrod, 2020).

The purpose and rationale of this paper is to describe a study protocol which includes a description of the Consortium members, the online instrument used for data collection, coupled with future work and dissemination activities. This study protocol details the urgency and the international response to the COVID-19 pandemic. We anticipate the preliminary findings will provide an insight into the use of digital technologies and the impacts of using digital technologies on psychological well-being and loneliness.

BACKGROUND AND LITERATURE REVIEW

Interdisciplinary Research Projects

In what follows we summarize previous projects that have targeted individuals through using online tools to collect data across different countries and individual's age-groups.

The ACT (aging + communication + technologies) project (ACT project, 2014–2021) is a Canadian-funded partnership that brings more than 45 international researchers, community partners and institutions together. By means of different pilot projects and case studies, ACT aims to explore and understand the transformational experiences of aging through various mediums of communication. It develops research in three main areas.

First, "Agency in Aging" encompasses a program of research that involves individuals and communities in the development of participatory action research projects in the field of the digital arts that have both scholarly and creative outcomes. Second, "Critical Mediations" examines the everyday life practices, the various mediated experiences of adults in later life, and the existing cultures of aging. Finally, "Telecommunication Technologies" investigates aging in the context of networked societies. Of interest to this paper are two cross-country projects, one which consists of an online longitudinal study about older audiences in the digital media environments and another, Grannies on the Net, about the role of information and communication technologies (ICTs) in grandmothers' interactions with close and distant social ties.

The online longitudinal research about older audiences in the digital media environments (2016–2020) (Loos et al., 2018, 2019) has revealed the rather diverse media practices (both digital and analog) and the heterogeneity of older online technology users among the six countries which are part of the project. This project underlines the importance of cross-national analysis when we talk about information communication technology (ICT) use by different generations. In analyzing data, researchers not only focused on the relation between well-being and media-based leisure of older adults (Gallistl and Nimrod, 2020) and on technology use by different generations of older adults (Ivan et al., Accepted), but also on media-displacement (Nimrod, 2019)–a process by which traditional media has been replaced to a more or lesser extent by the new media, in the way people communicate, get information, and solve everyday tasks.

The results of the Grannies on the Net project, which examines the role of ICTs in grandmothers' interactions with close and distant social ties, uncovered the varying motives and use strategies grandmothers deploy to communicate with a diversity of actors while revealing commonalities in the challenges they face in different cultural contexts. We tackled the role of ICT in reducing grandmothers' feeling of loneliness and their need to share everyday experiences with loved ones (Ivan and Hebblethwaite, 2016). Also, we analyzed the role ICT plays in older women's leisure (Nimrod and Ivan, 2019). On the one hand, it helps older women to remain active and socially engaged by saving time that could be used for their leisure, facilitating participation in various activities and allowing for a more meaningful leisure experiences both online and offline. On the other hand, ICT can often entail wasted time and disrupted involvement, or simply served as a "time filler." The authors of this respective study conclude how the impact of ICT may vary across various age cohorts and gender, which in turn may impact the various leisure activities by the respective participants.

The Technology In Later Life (TILL) project (2015–2017) is a multi-centered, international study comprising of two countries (UK and Canada) and four sites: two rural (South Wales, UK McBride, BC) and two urban (Milton Keynes, UK and Regina, SK). The TILL study aimed to explore the use, perceptions and impacts of technology on adults aged 70+ years residing in these four geographic locations. The findings from the TILL study ascertained two main overarching themes. The first is "facilitators of technology", which relates to the sharing of information by the respective participants, and for those participants who do use technology, the extent to which this afforded them a sense of security. The second theme is "detractors of technology", which identified a sense of apprehension of using technology. Recommendations from the TILL study proposed the notion of promoting technology based on the strengths and positive opportunities to facilitate health and well-being. Secondly, a peer support network(s) should be considered and created to assist novice users in understanding how to use ICTs facilitated by experienced peer users.

The notion of exploring and understanding how intergenerational relationships can be enhanced and maintained via technology use was also suggested (Marston et al., 2019). From a leisure standpoint, Genoe et al. (2018) identified technology as a primary means of accessing leisure activities such as games, hobbies and maintaining social connections. However, those participants did note challenges including, difficulty in using and updating software, concerns surrounding privacy and security and their overall lack of confidence and interest. Although technology may facilitate leisure activities and engagement from these respective participants, to overcome the issues and drawbacks identified by these participants may be afforded through educational/community opportunities.

Finally, intergenerational experiences were noted through data collection in the TILL study and were pivotal in continuing social connections with family and friends (Freeman et al., 2020). For example, findings showed older adults leveraged existing friendships and familial relationships when learning and adjusting to new digital devices and technologies. This is particularly the case when geographic distance is playing an integral role in these respective intergenerational relationships. The notion of a "digital gathering place" is motivated and implemented by all familial relationships and friends to ensure communication is continued.

The Technology 4 Young Adults (Technology 4 Young Adults (T4YA) Project, 2017) was a pilot study to understand the perception, use and impact technology has on young adults aged 18–34 years—the Millennials—in the UK. Findings from the T4YA initial study identified several primary themes including privacy issues and concerns, activities relating to content and sharing of information confidence, usability, and functionality of using technology and associated platforms coupled with various day-to-day activities (Marston, 2019).

The interdisciplinary research project "Internet and Mental Health" (2016–2019) aimed to investigate the psychosocial effects of using online media. In Germany, a nationally representative survey of 1,929 adolescents and younger adults (aged 14–39 years) focused on topics such as social media and gaming disorder (Reer et al., 2020; Tang et al., 2020a), the fear of missing out (Reer et al., 2019), or sexual harassment in online contexts (Tang et al., 2020b). A primary goal of this project was to examine how the use of ICTs is associated with different indicators of mental health, loneliness, depression, and anxiety. Findings from this project underline the central role of the Internet in the daily lives of the younger generation and emphasize its relevance for younger user's psychosocial well-being.

The "Being Connected at Home - Making use of digital devices in later life" project (BCONNECT HOME, 2018–2020) investigates fundamental changes in the contemporary experience of later life, at the intersection of digital infrastructures, place and the experience of "being connected" (Fernández-Ardèvol et al., 2019). It addresses a research gap by exploring and theorizing the role of digital communication devices—such as smartphones (that have been tracked), tablets, PCs, apps, fitness trackers, pedometers, or "brain games" —in relation to the modern life course. It combines this theoretical approach with a practical goal through co-design by involving diverse older people and other relevant stakeholders in "Academic Work Places" in the Netherlands, Spain, Sweden and Canada. The project is contextualized by debates around age in place, loneliness and social isolation, and the idea that these are age-related challenges that require interventions.

The ACCESS Project (Supporting Digital Literacy and Appropriation of ICT by older people, 2018–2021) aims to provide and evaluate socially embedded learning opportunities for older adults who are digitally excluded. The aim of the project is to support older adults to learn and appropriate new digital technologies later in life in Austria, Germany, Italy, Finland and Japan. It addresses a research gap by exploring informal, non-formal and formal learning settings in later life and further developing it through combination of such approaches with different forms of learning (courses, senior-to-senior approaches, praxlabs) (Gallistl et al., 2020).

The project "App-Solute News: Intergenerational Learning, Digitalisation and the Media" (2020–2022) looks at the daily routine of newspaper reading in the context of the transition from analog (printed paper) to digital (e-paper and app). Intergenerational teams of students and adults 60+ in the region of Styria in Austria will compare their reading habits, work with printed papers and e-paper apps, and create digital stories about their experiences. The aim is to investigate the narratives that are formed in these intergenerational encounters with regard to the transition from analog to digital. The project aims at understanding the role of age and age-related stereotypes in digitalisation processes.

Building upon the extensive projects conducted before, this study is expected to bring in a sociological lens to look into the influence of using digital technologies. The ongoing COVID-19 pandemic as a health crisis has resulted in the disruption of work, family support, education and social interaction. These changes may have formed heath, social and economic stressors to one's psychological well-being in the times of ongoing crisis. The stress-process model illustrates how economic strains and changing social circumstances become long-term stressors that impact individual health and well-being and how various sociodemographic groups may have different degrees of impacts (Pearlin et al., 2005). This framework provides a new perspective to look into the prevalence of how individuals from different sociodemographic backgrounds change to use the digital technologies and also provides explanations on the extent digital technologies influence individual well-being and loneliness to cope with the external pandemic.

While the aforementioned projects address issues related to the use and impact and appropriation of digital technology in people's lives, this paper reports on a study that, although addressing adjacent goals to those of the projects above, emerges in the context of the current COVID-19 pandemic scenario. Freeman et al. (2020) continue to note the importance of intergenerational support and communication, is having and has been pivotal since the start of the pandemic. Whereby, the use of various forms of digital technologies (e.g., communication tools and social media platforms) as a primary method of maintaining intergenerational social connectedness and support has been key. For example, for those older adults who do not have internet access, while their children or grandchildren who do have internet, has afforded the older person to be able to receive groceries during the strict lockdown(s) period. During the lockdown period of the pandemic and especially for those citizens in society categorized as vulnerable and who needed to shield, having access to the internet was key to ensuring day-to-day/monthly supplies of groceries as well as maintaining communication and leisure activities. The survey deployed in this study has and will capture the various activities of individual respondents and their communities during the pandemic. We anticipate we will be able to report findings surrounding what type of leisure activities have been conducted, the various community efforts employed (especially aimed at the vulnerable populations), and the health and well-being of respondents relating to social connection and loneliness.

METHODS

The project- COVID-19: Technology, Social Connections, Loneliness and Leisure Activities (2020a) has employed two theoretical theories, firstly a life course perspective (Elder, 1985; Green, 2017; Hutchinson, 2018). Taking a life course perspective will afford the Consortium to analyse the collected data to specific personal, and historical life events, forming a "personal biography" (Elder, 1985). This project is not primarily aimed at older adults but adults who are 18 years or older and given this unprecedented pandemic has impacted the lives of all citizens globally. Furthermore, taking a life course perspective will provide a quantifiable understanding of how digital technologies have been used by citizens and their respective experiences pre pandemic as well as during the pandemic.

Secondly, ecology theory will afford the Consortium to examine, explore and discuss the role played by digital technologies during the pandemic, as the medium to improve citizens' social connections, which in turn enables citizens social resources and support to reduce feeling of loneliness. Additionally, the ecology theory will facilitate application associated to 1. the levels of loneliness, 2. the decomposition of the user profile and, 3. to ascertain the types of digital technology used by citizens during the pandemic across four areas: 1. Individual, 2. Relationship (e.g., family, peers, and friends), 3. Community (e.g., groups, networks, workplace, neighborhoods), and 4. Societal (Berkes and Folke, 1998; Foxon et al., 2009;

Smith and Stirling, 2010; Anderies, 2014; McPhearson et al., 2016; Ahlborg et al., 2019).

Aims and Objectives

The aim of this paper is to describe the online instrument of the COVID-19: Technology, Social Connections, Loneliness and Leisure Activities (2020a,b). This online survey explores how digital technology was used, accessed, perceived and impacted the lives of citizens across 11 countries (UK, Malta, France, Germany, Austria, Romania, India, Singapore, Portugal, Spain, and Turkey) and 10 languages (English, German, French, Hindi, Mandarin, Portuguese, Romanian, Turkish, Spanish, Catalan). This will provide useful insights on the use of digital technologies and the impact of use on loneliness from the surveys across 11 countries.

The surveys across 11 countries under the project: COVID-19: Technology, Social Connections, Loneliness and Leisure Activities (2020a) have the following overarching objectives:

- explore the behavior and use of technology by citizens during the COVID-19 pandemic
- explore how citizens use technology to connect with COVID-19 support groups
- explore how citizens use technology to share information during the COVID-19 pandemic
- explore the health and well-being of citizens during COVID-19 relating to loneliness and digital health literacy
- explore the perception and notion of a national emergency alert system by citizens
- explore the behavior and narratives of users who are using technology to maintain familial and friendship social connections and build new connections during the COVID-19 pandemic.

As can be seen, these aims are incorporated into the online survey and will provide important data on how people have been using digital technologies and the differentiations of digital technologies during the pandemic. Moreover, the survey also covered health-related questions, which enable researchers to look into the health and well-being of the respondents.

Ethics

Ethical approval for conducting the online survey was initially granted by the lead and respective University, The Open University (HREC/3551/MARSTON) located in the UK.

Subsequent ethical approval has been processed and approved by the National University of Political Studies and Public Administration (SNSPA–Romania), Open University of Catalonia (Spain), Singapore University of Social Sciences (Singapore), Department of Health Sciences Management, University of Malta–(Malta), the Department of Informatics Engineering (DEI)/Center for Informatics and Systems (CISUC) at the University of Coimbra (Portugal), the Department of Mass Communication and Media Studies at the Central University of Punjab (India), Nursing Science, Age and Care Research Group at the Medical University Graz (Austria), Department of Sociology at the University of Vienna, the Department of Age and Care Research Group at the University of Graz (Austria), the Department of Communication at the University of Münster (Germany), and Canakkale Onsekiz Mart University in Turkey.

All versions of the survey, study information sheet and certification from respective Universities have been shared with The Open University Human Research Ethics Committee (HREC) to ensure those respective records are maintained and kept up to date.

All documentation lists the ethical approval granted by the lead University and the respective University ethical committee or board. Informed consent was obtained by all participants taking part in this online survey.

Partner Recruitment

Upon completion and deployment of the English version of the survey, the project lead (HRM) contacted colleagues in a bid to expand the survey and increase participant recruitment. This resulted in the lead for Romania (RO) requesting the word documents to be translated and rolled out across Romania.

This, in turn, led to the UK and RO leads utilizing their existing networks and inviting their respective colleagues to join the project. HRM provided a description of the study, responsibilities, and expectations to prospective partners, and once a partner confirmed their involvement, the English survey and study information sheet was provided to the respective partner to allow for back/translation to commence. A copy of the ethics application by HRM at The Open University was shared with the respective partner to facilitate the respective partner to expedite their own ethical approval process.

Participant Recruitment

Given the focus of this work and the restrictions imposed by the respective Universities and Countries, participant recruitment is being conducted through multiple channels in what constitutes a *non-probabilistic* sampling process, usual in online research (Ayhan, 2011). This includes social media channels (e.g., Facebook, LinkedIn, Twitter, WhatsApp), existing mailing lists, stakeholder organizations (e.g., Age Northern Ireland). Subjects aged 18 years and older are allowed to take part in the online survey.

To obtain insights into the current COVID-19 health crisis during the lockdown period, a virtual *snowball sampling technique* is applied through the project team's networks to build a sample quickly and across different countries. This technique is increasingly applied given the facilities that the Internet opens to investigate phenomena in current societies (Benfield and Szlemko, 2006; Baltar and Brunet, 2012). This approach has advantages such as reaching individuals faster (hence minimizing the period of collecting and processing data), expanding the sample size and the scope of the study across different settings (e.g., different countries) given the flexibility to apply them in different formats and languages. Nevertheless, this approach also has some shortcomings, such as *selection bias* related to the online population reached and the non-representativeness of the sample to the general population, aspects that should be considered when analyzing the data. Additionally, India chose to recruit participants using an alternative approach to the other countries, and includes using a direct WhatsApp link, followed by

TABLE 1 | Demographic characteristics of the countries included in this study (United Nations, (2019); The World Bank Group, (n.d.); Worldometer, (n.d.-a), (n.d.-b)).

Country	Total population	Population density/Km^2	Median age	Life expectancy at birth	World share of population	Economic group
Austria	9,006,398	109	43	82.05	0.12%	High-Income
France	65,273,511	119	42	83.13	0.84%	High-Income
Germany	83,783,942	240	46	81.88	1.07%	High-Income
India	1,380,004,385	464	28	70.42	17.70%	Lower-Middle Income
Malta	441,543	1380	43	83.06	0.01%	High-Income
Portugal	10,196,709	111	46	82.65	0.13%	High-Income
Romania	19,237,691	84	43	76.50	0.25%	High-Income
Singapore	5,850,342	8358	42	86.15	0.08%	High-Income
Spain	46,754,778	94	45	83.99	0.60%	High-Income
Turkey	84,339,067	110	32	78.45	1.08%	Upper-Middle-Income
United Kingdom	67,886,011	281	40	81.77	0.87%	High-Income

frequent follow-ups. The approach was deemed by the respective partner as a means of encouraging prospective participants to participate in this survey. Furthermore, this approach provides a more personalized approach in helping to get good numbers of responses within an Indian context.

Currently, some surveys are still ongoing, and it is not possible to provide a complete overview of participant demographics of this study. However, the 11 study sites involved in the project include an interesting subset of countries, representing different socio-economic groups and population characteristics (**Table 1**). This will lend the project and the collected data to include and report diversity. Furthermore, this will provide insight concerning countries of high, middle, and low-income, surrounding different demographic characteristics, for example population densities, median age, life expectancy, etc. Overall, the countries involved in this study represent ∼22% of the world share of the population.

Online Survey

The online survey rolled out for the study uses the Qualtrics platform as the sole method of deployment across different networks. The English version of the survey is based on previous iterations and studies conducted by the lead author (Marston, 2012, 2019; Marston et al., 2016, 2019). During the design of the English version of the survey, revisions were conducted to the instrument to meet the aims and objectives of the study.

For a new survey to be added to the Qualtrics platform, a copy is made within the platform and the lead author transfers (manually, copy and paste) the translated version of the survey into the new project. The project is named in that respective language. Once the translation is transferred, the survey is exported into Microsoft Word, saved, and shared with the partner(s) to review for any errors, changes in questions to reflect the cultural context and resent for amendments within the Qualtrics platform. In some instances back to HRM, the survey may have several colleagues from one institution reviewing the documentation and suggesting revisions. Once the respective partners have agreed that the documentation is correct, the respective online measuring instrument goes through some usability testing, on various hardware devices, and changes are suggested. Once this stage has been agreed, the instrument is copied again, and republished, in preparation for rollout.

Survey Languages and Translated Versions

Table 2 presents the versions of the survey, translated languages and the lead for each country. At present there are 10 countries which currently have the survey deployed and staggered rollout dates because of ethical approval. Survey versions by additional partners will be open for 3 months respectively upon ethical approval and rollout.

Measures

The surveys build on previous iterations from the Technology 4 Younger Adults (T4YA) study (Marston, 2019), the iStoppFalls EU project (Marston et al., 2016), the Technology In Later Life (TILL) project (Genoe et al., 2018; Marston et al., 2019; Freeman et al., 2020), and the doctoral work of HRM (Marston, 2012).

In total there have been seven scholarly works published using earlier iterations of this survey (Marston, 2012, 2019; Marston et al., 2016, 2019; Genoe et al., 2018; Freeman et al., 2020). An earlier iteration of a survey deployed in the TILL study is available for download (Marston et al., 2019). The previous version of the survey deployed in the TILL study comprised an 80-item survey.

This new iteration of the English version of the survey comprises 65-items (**Table 3**). For some of the languages/countries there have been some minor alterations to the survey to represent each country's respective culture, laws, and educational systems. For example, the Singapore arm requested the questions relating to sexuality should be deleted for both the English and Mandarin versions which would be rolled out across the respective networks. The consideration is due to the fact that Singapore still retains the section 377A of the Penal Code (Singapore Statues Online, 2020). Though the law is not enforced (Chen, 2013), the partner for the Singapore arm decided to revise the question about the sexuality to a conventional question of the participants' gender with an option where participants can fill out the identity freely. The French partner also requested the questions on sexual

TABLE 2 | Displays the survey iterations.

#	Lead	Country	Language	Countries deployed	Survey deployment	Ethical approval
1	Hannah R. Marston, Sarah Earle	UK	English	USA, Canada, Singapore, Australia	03.04.2020	Approved
2	Loredana Ivan	Romania (RO)	Romanian	Romania	20.04.2020	Approved
3	Mireia Fernández-Ardèvo, D. Blanche Tarragó, A. Rosales Climent, M. Gomez Leon	Spain	Catalan Spanish	Spain and Hispanic America	04.05.2020	Approved
4	Sophie Colas	France	French	France, Switzerland, Belgium, Quebec (CA)	12.05.2020	Approved via The Open University
5	Pei-Chun Ko	Singapore	Mandarin	Singapore	12.05.2020	Approved
6	Halime Öztürk Çalikoğlu, Hasan Arslan, Burcu Bilir	Turkey	Turkish	Turkey	26.06.2020	Approved
7	Rubal Kanozia	India	Hindi	India	31.05.2020	Approved
8	Vera Gallistl, Ulla Kriebernegg, Franziska Groβschädl, Gerhilde Schüttengruber, Rebekka Rohner, Hanna Kottl	Austria	German	Germany,Switzerland	05.06.2020	Approved
9	Feliz Reer, Thorsten Quandt	Germany	German	Austria/Switzerland	04.06.2020	Approved
10	Sandra C. Buttigieg	Malta	British English	Malta	19.05.2020	Approved
11	Paula Alexandra Silva	Portugal	European Portuguese	Portugal	29.05.2020	Approved

orientation and transgender identity to be removed due to its too intimate nature.

Furthermore, a slight change in wording for questions relating to the national emergency alert system were renamed to "Public Warning System" in Singapore. Both versions in India (English and Hindi) as well as the version in European Portuguese, French and German do not include the question relating to ethnicity. In some instances, the types of educational qualification were altered to represent the respective cultural contexts. This occurred for translations in Catalan and Spanish, European Portuguese, and German. The Spanish version was also aimed at rolling out in extended networks across Hispanic America. Additionally, in both the Catalan and Spanish versions the questions relating to a national emergency alert system were deleted, and this was on the guidance of the partners in the project, because they felt that in their targeted countries there were either no such systems in place, or no public discussion on the matter, making the question difficult to answer in most instances.

Procedure

The project lead for the UK shares a copy of the study information sheet and a copy of the English survey with the new consortium partner. If a partner has additional colleagues, communication is limited to reduce the risk of information being misunderstood and to ensure all communication between the two coordinators is correct. This is a practical approach during the survey translation(s) and testing phases.

Each new country/partner applies for ethical approval through their respective University ethics committee. Additional documentation from the UK partner is shared based on the favorable opinion granted by the Open University (HREC/3551/MARSTON). A copy of the ethics application is also shared to assist the respective partner in completing their ethics application. Furthermore, each partner has the option to attach this document and the favorable opinion to their respective application.

The Qualtrics platform is used to create and deploy the survey to adhere to the Open University policies. All translated surveys from each study partner are transferred into a new project within the platform and exported to Microsoft Word for checking by the Consortium partner. Each revision within the platform is published and allows the consortium partner to test their respective survey for user experience (UX)/usability issues and formatting. At each revision, the consortium partner receives an updated version of the survey via a Word document and is able to review the survey online.

Survey Deployment

Once ethical approval is granted, the survey was "published" via the Qualtrics platform, which created an independent link that is shared via various channels (specific email(s), anonymous link etc.). The COVID-19: Technology, Social Connections, Loneliness and Leisure Activities (2020b) project website is the portal for all participants to review the study, download the respective study information sheet, and access the online survey.

To assist prospective participants to identify the correct survey to complete, a series of flags are placed at the side of each translated section (**Figures 1**–**4**). To ensure access to the study information sheet and the respective online survey—there are links in the respective language which highlights the links—"Study Information Sheet" and "Complete Online Survey Here". The size of the flags helps identify the desired version of the survey. However, an issue that might prevent participants to reach their survey is that the webpage is only available in English.

TABLE 3 | Presents an overview of the measuring variables included in the COVID-19 technology, self-isolation, health, well-being, and leisure activities study.

Survey section	Survey items	Example of question(s)	Source
Participant Consent Q1	Participant consent	NA	NA
Section A Q2–Q16	Computer ownership, purpose of using a computer, length and frequency of use, video game console ownership, favorite type of game to play. How the internet is accessed, frequency of using the internet, purpose of using the internet. Type of social media platforms used, frequency and purpose of using social media platforms.	• Have you used a computer? (select answer) • How long have you used a computer for? (select answer) • Do you use social networking sites • Why do you use social media sites	(Marston, 2012, 2019; Marston et al., 2016, 2019; Genoe et al., 2018; Freeman et al., 2020)
Section B Q17–35	COVID-19 related questions: purpose of using technology/internet/social media platforms to share information, communicate with support groups, challenges faced during COVID-19.	• Since COVID-19, have you become a member of a community support group on social media (e.g., Facebook or similar)? • Since COVID-19, have you signed up to receive community deliveries/assistance (e.g., groceries from a local newsagents /community shop / butcher's / farmer's market)? • Please describe why you WOULD sign up to receive community deliveries and/or assistance. If you choose not to answer please write N/A • Please describe why you are unsure or you WOULD NOT sign up to receive community deliveries and/or assistance. If you choose not to answer please write N/A • Since COVID-19, how have you been spending your time? Select all that apply • My death and that of people close to me (e.g., family members) • Limited social contact with friends and family • Not having a job to go back to • I am on my own. I have no support (e.g., no children etc.) • Education for my child/children • On your digital device do you share information about COVID-19? • Why do you share information surrounding COVID-19–select all that apply	Q17-25 - new items added aimed specifically at Covid-19 experiences. Q26-35 - adapted from (Genoe et al., 2018; Marston, 2019; Marston et al., 2019; Freeman et al., 2020)
Section C Q36–Q40	13-items, 1–7 pt Likert COVID-19 related questions	• Making new social connections/friendships • Spending more time with spouse/family members • Being a key worker and helping in this pandemic • Being isolated more • Giving something back • Please describe how your communication behavior(s) has changed since COVID-19. If you choose not to answer please write N/A • Since COVID-19, has the way you use your digital devices changed your way of communication?	New items added relating to Covid-19
Section D Q41	18-item measure, 1–7 pt Likert Psychological well-being	• "I am good at managing the responsibilities of daily life." • "I think it is important to have new experiences that challenge how I think about myself and the world." • "I judge myself by what I think is important, not by the values of what others think is important."	Ryff and Keyes, 1995; Ryff and Singer, 1998
Section E Q42	8-item measures, 1–5 pt Likert scale eHealth/digital literacy	• I know where to find helpful health resources on the Internet • I know how to use the health information I find on the Internet to help me • I feel confident in using information from the Internet to make health decisions	Norman and Skinner, 2006
Section F Q43	UCLA Loneliness scale Version 3, 20-item measure, 1-4 pt Likert scale	• How often do you feel that you are "in tune" with the people around you? • How often do you feel part of a group of friends? • How often do you feel that your interests and ideas are not shared by those around you? • How often do you feel that no one really knows you well?	Russell, 1996
Section G Q44–Q49	Social networks, virtual assistants and emergency alert systems	• During the COVID-19 pandemic, how frequently have you communicated with members of your social network? Please rate your answers below on each of the sliders • Does your country have a National Emergency Alert System (e.g., mobile app or SMS)?	

(Continued)

TABLE 3 | Continued

Survey section	Survey items	Example of question(s)	Source
		• Please describe what your thoughts are relating to a National Emergency Alert System (e.g., mobile app or SMS)? If you choose not to answer please write N/A • Virtual Assistants such as Alexa, Google Home, Siri have various features. Please describe whether you think such devices or similar would be suitable as a way of sharing National Emergency Alert Systems. If you choose not to answer please write N/A	New items added to the survey.
Section H Q50–Q65	Demographic questions: gender, age, country, ethnicity, geographic location, education, sexuality, marital status, #of people living your home, #of children living your home, employment status, disability, self-isolation	• Do you meet the criteria for being vulnerable or extremely vulnerable? • Have you had to self-isolate because of COVID-19?	(UK Government, (n.d.); Marston, 2012, 2019; Patten, 2015; Marston et al., 2016, 2019; Genoe et al., 2018; Settlement Hierarchy, 2019; Thrive, 2019; Education in the United States, 2020; Freeman et al., 2020)

FIGURE 1 | Figure displays three partners involved in the study and their respective flags, study information, contact information. For each partner/country, there were additional links to the online survey, study information sheet, and consent form.

For each country/consortium partner, there is a contact email address available on the study website and the study information sheet. This facilitates the participant(s) to contact the researcher in charge of the survey in each particular language (**Figures 1**–**4**).

Data Analysis

In this section of the study protocol, we outline how the collected data and subsequent analysis will drive the results forward. Each survey translation closes at various times and at present between 4th July and 29th September 2020. The data analysis will take the form of descriptive statistics with crosstabulations and multivariate regression models to provide preliminary descriptive findings. This in turn will drive the results to afford the Consortium members to explore and understand the collected data from the standpoint of (a) age, (b) gender, (c) education, and (d) country. *T*-tests will be employed to test the differences in the levels of well-being and loneliness feelings among different social groups based on sociodemographic characteristics. Lastly, inferential statistical analysis will be conducted to examine the relationships between digital use and well-being and/or loneliness feelings, with the considerations of different sociodemographic, family structure, and country settings (especially related to COVID-19 measures) of respondents.

Our sample is a convenience sample in all countries included in the study and we do not claim to have statistical and national representative at the country level. Still, we will conduct further analysis if the structure of our sample in each country is comparable with the structure of the adult population with Internet access (age, gender, education level and economic status).

To consider the differences across the countries and cultures included in the study, this project relies on a research team that consists of native speakers and local researchers, who are and will play an important role in contextualizing the respective data. Additionally, members of the research team have the role in comparing the data across the main socio-demographics (age, gender, level of

FIGURE 2 | Figure displays three partners involved in the study and their respective flags, study information, contact information. For each partner/country, there were additional links to the online survey, study information sheet, and consent form.

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education, economic status) and to provide valuable information regarding the comparability of the sample in the current proposal with the structure of the total adult population in the respective countries.

We anticipate the collected data will provide an insight into the prevalence of different types of digital technologies with the crosstabulations of various sociodemographic characteristics. While each study site will be conducting their own data analysis, we will also be merging the different data sets into STATA to facilitate greater statistical analysis via multivariate analyses to understand the impact(s) of digital technologies on well-being and loneliness. All surveys will be closed by the end of September.

Online Repository

As part of the ethical process at The Open University an online repository is used—Open Research Data Online (ORDO). A separate project has been created by the lead, and all partners have been invited to join the project. ORDO will be used to store all final documents, data and associated information relating to this study. Each country/region has its individual folder to facilitate ease of organization, access and following the policies of The Open University.

The Consortium

This is a cooperative project that responds to the need of urgent information during the unexpected COVID-19 pandemic.

FIGURE 4 | Figure displays three partners involved in the study and their respective flags, study information, contact information. For each partner/country, there were additional links to the online survey, study information sheet, and consent form.

The project lead has already defined the operational dynamics of the study to grant fast and sustainable outputs (academic journals, policy recommendations) as well as other dynamics in search of the establishment of a consortium able to create an intellectual community around the gathered data. Each study site has worked with the project lead to ensure the translated survey has conducted backwards translation of the online survey and to ensure the meaning(s) of the survey questions are not lost. Each site lead was responsible for their own participant recruitment—via mailing lists, various social media channels (e.g., Twitter and Facebook) and will be responsible for data analysis.

DISCUSSION AND FUTURE WORK

In this study protocol we are describing how this international, multi-centered project has been designed to explore and understand how digital technology and associated platforms are being used by citizens and how digital technology impacts on their day-to-day lives during the COVID-19 pandemic, across different countries, regions and cultures. With this in mind, participants of the study are welcome to complete a survey if they are over 18 years old. Given the unprecedented crisis on a global scale, citizens in society are living and experiencing life differently to what society was prior to the pandemic and also differently depending on the country they live in. Therefore, it is important to explore how technology is having an impact on citizens from the age of 18+ years, rather than just focusing on older adults as this will allow for comparisons between generations.

In particular, it is essential to capture the possibilities that digital technology affords citizens during this pandemic a as way of garnering insights with the view to working toward respective pathways to impact, which in turn has the ability to inform policy and decision makers at local, regional,

national and international levels. The fact that this survey is being deployed across several different languages, affords the Consortium members to reach out and understand different cultures and demographics. Furthermore, this project lends itself to understanding the necessary multidimensional perspective required to develop effective and meaningful pathways associated to social science and behavioral research, public engagement, knowledge translation and pathways to impact in the future. Moreover, this international project affords the Consortium partners to understand how digital technology is used and impacts society at a time when social distancing measures were varied and may afford the research team to understand and explore possible suggestions and solutions to feed into policy.

This study protocol describes the COVID-19: Technology, Social Connection, Loneliness and Leisure Activities project and we anticipate the findings driven from the collected data will contribute to the fields of gerontechnology, Human Computer Interaction (HCI), gerontology, and social sciences by the creation of a Master dataset and individual datasets from each site. Furthermore, this research will contribute to the existing scholarly research (Morris et al., 2014; Baker et al., 2018; Barbosa Neves et al., 2019; Ammar et al., 2020a,b,c; Fakoya et al., 2020; Marston and Morgan, 2020; Marston et al., 2020; Seifert et al., 2020). The Consortium anticipates the findings from the collected data will indicate how digital technology and associated platforms impact the lives of citizens across various sites during the pandemic. This will afford researchers, stakeholders and policy makers the opportunity in the future to learn and understand how citizens in the respective countries utilized digital technologies during unprecedented times. Additionally, the Consortium will be undertaking a wide variety of public engagement and knowledge translation activities, in addition to ensuring traditional academic outputs are achieved. Members of the Consortium will seek out opportunities to share findings with respective countries at local, regional and national levels of policy in a bid to offer insights and solutions in the future.

Currently, existing scholarly research demonstrates the growing interest in contemporary academe surrounding the use of digital technology as a bridge to maintain social connections and interactions while reducing loneliness; with the aim of understanding how technology has impacted the lives of many citizens worldwide. This study protocol describes how this particular study, to the knowledge of the Consortium, is the first to take an international, interdisciplinary rapid response to the COVID-19 pandemic, while contributing to existing respective disciplines.

The social impacts of the pandemic can be understood through the lens of the digital divide with the intersectionality of education, gender and age. The project is expected to bring in first-hand data to understand the prevalence of technology associated to the different socio-demographic groups. This in turn will afford us to understand whether the COVID-19 pandemic narrows the digital gap or widens it. Incorporated with the loneliness scale and the questions of the activities, researchers can examine the extent to which digital technology use influences individuals' mental well-being and social connections, and the heterogeneity among social groups.

Future work surrounding the Consortium members and the collected data will explore funding opportunities to enable the next phase of this project—pathways to impact and dissemination activities. The former may include an Open Educational Resource (OER) developed and accessible via The Open University which will include input from all project partners and will include content related to the findings. This in turn will enable citizens, policy makers, stakeholders, and researchers on a global scale to access, learn, and understand how digital technologies played a role and impacted the lives of citizens across 11 countries. Dissemination activities will include traditional academic outputs (e.g., journal papers and conference presentations), seminars, booklets/reports and where appropriate contributing to policy.

ETHICS STATEMENT

The studies involving human participants were reviewed and approved by The Open University (UK) HREC/3551/MARSTON. Written informed consent to participate in this study was provided by the participants' legal guardian/next of kin. All study sites received ethical approval prior to survey deployment. The French version of the online survey was approved via the Open University.

AUTHOR CONTRIBUTIONS

HM: conceptualization. HM, LI, MF-A, AR, MG-L, DB-T, SE, P-CK, SC, BB, HÖ, HA, RK, UK, FG, FR, TQ, SB, PS, VG, RR, and the COVID19 Technology Consortium Group: writing – original draft preparation, review, and editing. All authors contributed to the article and approved the submitted version.

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Patient Flow Dynamics in Hospital Systems During Times of COVID-19: Cox Proportional Hazard Regression Analysis

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Bhandari S, Tak A, Singhal S, Shukla J, Shaktawat AS, Gupta J, Patel B, Kakkar S, Dube A, Dia S, Dia M and Wehner TC (2020) Patient Flow Dynamics in Hospital Systems During Times of COVID-19: Cox Proportional Hazard Regression Analysis. Front. Public Health 8:585850. doi: 10.3389/fpubh.2020.585850

Objectives: The present study is aimed at estimating patient flow dynamic parameters and requirement for hospital beds. Second, the effects of age and gender on parameters were evaluated.

Patients and Methods: In this retrospective cohort study, 987 COVID-19 patients were enrolled from SMS Medical College, Jaipur (Rajasthan, India). The survival analysis was carried out from February 29 through May 19, 2020, for two hazards: Hazard 1 was hospital discharge, and Hazard 2 was hospital death. The starting point for survival analysis of the two hazards was considered to be hospital admission. The survival curves were estimated and additional effects of age and gender were evaluated using Cox proportional hazard regression analysis.

Results: The Kaplan Meier estimates of lengths of hospital stay (median = 10 days, IQR = 5–15 days) and median survival rate (more than 60 days due to a large amount of censored data) were obtained. The Cox model for Hazard 1 showed no significant effect of age and gender on duration of hospital stay. Similarly, the Cox model 2 showed no significant difference of age and gender on survival rate. The case fatality rate of 8.1%, recovery rate of 78.8%, mortality rate of 0.10 per 100 person-days, and hospital admission rate of 0.35 per 100,000 person-days were estimated.

Conclusion: The study estimates hospital bed requirements based on median length of hospital stay and hospital admission rate. Furthermore, the study concludes there are no effects of age and gender on average length of hospital stay and no effects of age and gender on survival time in above-60 age groups.

Keywords: COVID-19, cox proportion hazards models, evidence based decision making, hospital beds, public health, hospital management

KEY MESSAGES

- Patient flow dynamic models are useful in management of the COVID-19 pandemic.
- Hospital data on admission and discharge can be used to estimate parameters of the model, such as hospital admission rates, recovery rates (inverse of median length of hospital stay).
- Real-time demand of hospital beds can be found based on estimated parameters.
- Evidence-based decision making is the best way to combat this pandemic.
- The intensity of public health measures implemented should be based on parameter values.

INTRODUCTION

According to the World Health Organization, on June 22, 2020, there were 8,860,331 confirmed cases and 465,7440 deaths due to COVID-19 (1). The dynamics and course of COVID-19 are uncertain, and it is not merely possible but likely that the patient load will overwhelm the medical infrastructure, including hospital beds and medical equipment. The emergence of a pandemic leads to extraordinary demands on the public health system. The number of hospital beds occupied is a function of median length of hospital stay and admission rate (2). The public health measures during the management of a disease pandemic should be aimed at increasing hospital bed capacity and decreasing admission rates as well as the length of the median hospital stay. Currently, no pharmaceutical interventions are safe and effective; however, best practices for disease management are based primarily on non-pharmaceutical measures, including a ban on public gatherings, compulsory home stays, closure of religious and educational institutions, closure of non-essential businesses, face mask ordinances, quarantine, and *cordon sanitaire* (that is, a defined quarantine area from which those inside are not allowed to leave) (3). A number of mathematical models have been proposed to estimate the hospital bed capacity during the pandemic (4–6). The estimation of parameters is required for further analysis by such models.

The present study is an effort to estimate the dynamic parameters of the COVID-19 pandemic, including median length of hospital stay, median survival time, mortality rate, recovery rate, hospital admission rate, and case fatality rate in a tertiary care hospital. Further comparison of survival data across gender and age groups was performed using Cox proportional hazard analysis. Against the background of given parameters, the outcomes of public health policymaking can be evaluated. The rationale of evidence-based decision making can be fulfilled.

MATERIALS AND METHODS

In this hospital-based retrospective cohort study, 987 COVID-19 patients (confirmed with real-time RT-PCR) were enrolled from February 29 to May 19, 2020, from SMS Medical College and Hospital, Jaipur, Rajasthan, India. Survival analysis was carried out to estimate median hospital stay and median survival time. The effects of age and gender on survival patterns were evaluated using Cox proportional hazard regression analysis. Furthermore, case fatality, mortality, recovery, and hospital admission rates were also estimated. The duration of the study was 81 days.

Data Collection

The age, gender, and dates of hospital admission and discharge were recorded from case sheets of patients. The hospital outcome, i.e., recovered, died, or admitted, was also recorded. Hazard 1 was considered to be hospital discharge or death. Survival time 1 (ST1) was calculated from a starting point as the date of hospital admission and an end point as the date of hospital discharge or death (Hazard 1). The cases admitted on the last day of the study were still considered under censored observations (censoring 1). Similarly, Hazard 2 was considered to be death in the hospital of patients over 60 years of age. Survival time 2 (ST2) was calculated as the period between the date of hospital admission (as all patients tested RT-PCR positive were hospitalized) and date of death (Hazard 2). The cases that were still admitted or recovered were considered under censored observations (censoring 2).

Data Analysis

As the data was continuously observable, the survival analysis was done with the help of the Kaplan Meier (K-M) method. The survival rate was defined as a cumulative probability distribution function (cdf) of survival time ($P[ST \geq t]$, where t is time). Survival rates 1 (SR1) and 2 (SR2) for Hazards 1 and 2 were calculated.

In order to evaluate the effects of age and sex on survival patterns, two Cox proportional hazard models (Cox models 1 and 2) were fitted for Hazards 1 and 2, respectively. The covariates used in both models were age and gender. Before analyzing data in the Cox model, we checked to make sure censoring did not vary significantly for different values of covariates. The hazard ratios were calculated for both models (7).

The case fatality, mortality, recovery, and hospital admission rates were calculated as below (8):

$$\textit{Case fatality rate}\ (\%) = \frac{\textit{Total number of deaths}}{\textit{Total number of COVID} - 19\ \textit{cases}} \times 100$$

$$\textit{Recovery rate}\ (\%) = \frac{\textit{Total number of recovered}}{\textit{Total number of COVID} - 19\ \textit{cases}} \times 100$$

$$\textit{Mortality rate}\ (\textit{per}\ 100\ \textit{PD}) = \frac{\textit{Total number of deaths}}{\textit{Total observed time}\ (\textit{person} - \textit{days})} \times 100$$

$$\textit{Hospital admission rate}\ (\textit{per}\ 10^5\ \textit{PD}) = \frac{\textit{Total admissions}}{\textit{population} \times \textit{days}} \times 10^5$$

For the estimation of hospital admission rate, the population of Jaipur was considered to be 3.47 million (9).

Abbreviations: cdf, cumulative probability distribution function; CI, confidence interval; COVID-19, coronavirus disease-19; K-M, Kaplan Meier; HR, hazard ratio; *p*, *p*-value; SARS CoV-2, severe acute respiratory corona virus 2; SR1, survival rate 1; SR2, survival rate 2; ST1, survival time 1; ST2, survival time 2.

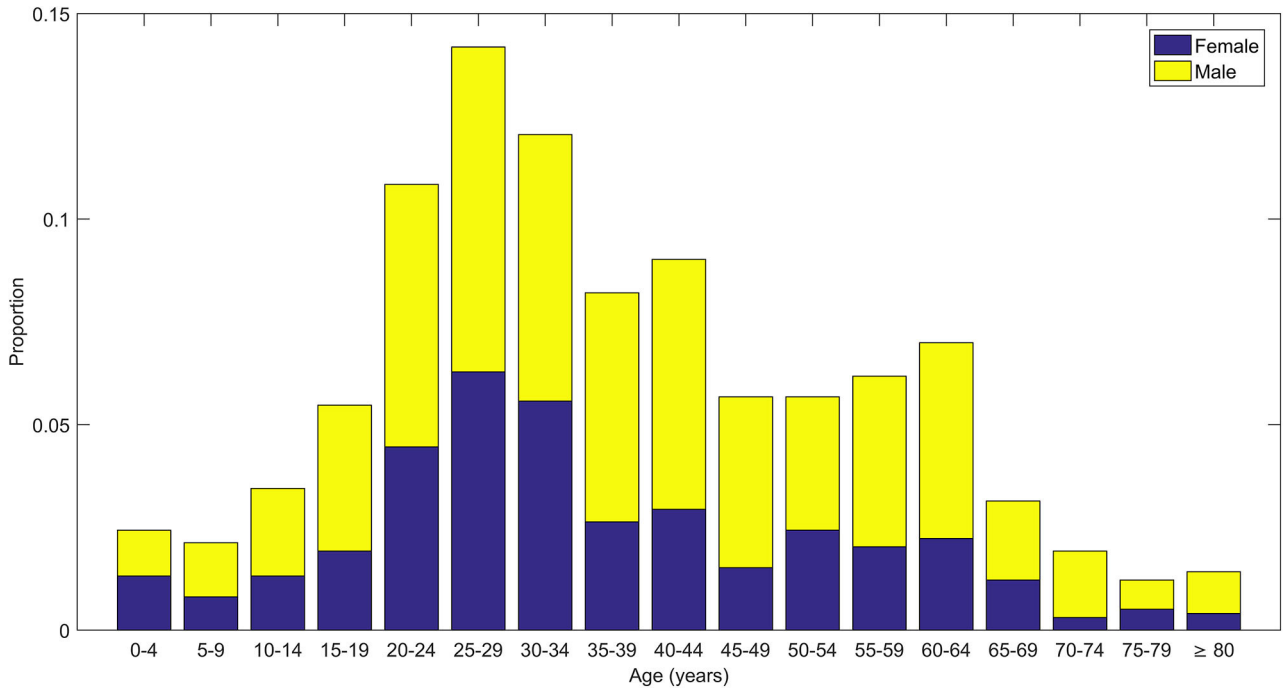

FIGURE 1 | Stacked bar plots showing distribution of age of COVID-19 cases along with distribution of gender (male and female) within each age group.

TABLE 1 | Descriptive statistics of age and sex along with comparison of age and gender across recovered and death cases in COVID-19 patients.

Variables		Total ($N = 987$)	Recovered cases ($N = 778$)	Death cases ($N = 80$)	Statistics*	df#	p
Age		34 (25, 50)	33 (24, 47.75)	55 (35, 65)	6.09	91	< 0.001
Sex	Male	62.11%	55.94%	5.94%	0.13	1	0.72
	Female	37.89%	34.73%	33.79%			

*Welch test was used to compare age in recovered and death cases and chi-squared test was used to find association between sex and cases.
#df: degrees of freedom; Median age and 1st and 3rd quartile is expressed in parenthesis.

Statistical Analysis

The quantitative variables were expressed as median survival time and 95% confidence intervals with K-M based standard errors for the estimates of the Cox proportional hazard regression model. The statistical level of significance was considered at 5%. For the statistical analysis, we used JASP version 0.11 software and MATLAB 2016a (10, 11).

RESULTS

The mean age of COVID-19 cases was 37.08 years (SD = 17.87). Men (62.11%) had a higher proportion of COVID-19 than women (37.89%). The distribution of age and gender indicated that younger men were most affected (**Figure 1**). The distribution of age and outcome showed a higher proportion of deaths in the elderly (**Tables 1**, **2**).

Survival Curves

The survival curve and K-M estimates for Hazard 1 were obtained (**Figure 2**, **Supplemental Table 1**). The median ST1 (median hospital stay) was 10 days.

The survival curve and K-M estimates for Hazard 2 were obtained (**Figure 3**, **Supplementary Table 2**). The median ST2 was more than 60 days because most of the data was censored.

Cox Proportional Hazard Analysis

The censored and uncensored data for Hazard 1 did not differ significantly in mean age ($t = 0.19$, $p = 0.85$) and gender ($\chi^2 = 0.13$, $p = 0.71$). Therefore, Cox model 1 was run with age and gender as covariates. Similarly, for Hazard 2, there was no significant difference found in mean age ($t = 0.71$, $p = 0.48$) and gender ($\chi^2 = 0.26$, $p = 0.61$). Therefore, Cox model 2 was also run with age and gender as a covariate.

The Cox Model 1 for SR1 showed no significant effect of age (HR = 1.00, $p = 0.05$) or gender (HR = 0.98, $p = 0.88$). Similarly,

TABLE 2 | Association of mortality and various age groups in COVID-19 patients.

Age group (Years)	Mortality status		
	Death	Recovered	Total
0-4	3	17	20
5–9	0	17	17
10–14	1	31	32
15–19	1	52	53
20–24	8	82	90
25–29	2	113	115
30–34	4	100	104
35–39	4	66	70
40–44	3	79	82
45–49	5	43	48
50–54	8	43	51
55–59	7	42	49
60–64	13	45	58
65–69	10	20	30
70–74	3	13	16
75–79	5	5	10
80	3	10	13
Total	80	778	858

for SR2, the Cox model 2 showed no significant effects of age (HR $= 1.01$, $p = 0.62$) or gender (HR $= 1.15$, $p = 0.69$).

Estimated Rates

The case fatality rate was estimated to be 8.1% (95% CI: 6.4–9.8%). The estimation of recovery rate was 78.8% (95% CI: 76.2–81.3%). The mortality rate was 0.10 (95% CI: 0.08–0.12) per 100 person-days, and the hospital admission rate was 0.35 (95% CI: 0.33–0.37) per 100,000 person-days.

DISCUSSION

The air we breathe, the food we eat, the house in which we live, the viruses to which we are exposed, the health services to which we have access, and the environment in which we live decide the outcome of a pandemic. The COVID-19 disease patterns are linked to migration, population movement, and disease diffusion (12). The main cause of varying rates of evolution of COVID-19 has resulted from different public health policies in various states (13). The primary objective for management of a pandemic is to keep the rate of evolution of cases lower such that the disease will not overwhelm the hospital bed capacity of any state. The aim of the management is to maintain the given inequality (2) (see **Supplementary File** for details):

$$Hospital\ capacity\ of\ the\ system\ \geq median\ LOS\ \times HAR\ \times N$$

where LOS is length of hospital stay, HAR is hospital admission rate (in 10^5 person-days) and N is the population (10^5 persons) dependent on the hospitals.

The present study estimated variables on the right side of the inequality. In order to maintain the inequality, hospital capacity should be increased or median hospital stay should be decreased or admission rate should be decreased. The hospital capacity of Jaipur was found to be 6,280, and the right side of the inequality was 108.5, which is less than hospital capacity (14). The rate of evolution for COVID-19 in Rajasthan was among the top eight states (15, 16).

As of now, no pharmaceutical agents are proven to be safe and effective for decreasing median hospital stay. The primary strategy is focused on non-pharmaceutical interventions (NPI) to decrease admission rates. Current control measures aim to reduce disease transmission through bans on public gatherings, compulsory home stays, closure of religious and educational institutions, closure of non-essential businesses, face mask ordinances, quarantine, and cordon sanitaire (that is, a defined quarantine area from which those inside are not allowed to leave) (3). Ravaghi et al. reviewed methods for determining optimum hospital capacity. The main factors were average length of hospital stay, admission rate, discharge rate, and target bed occupancy rate (2).

A number of mathematical models have been used in the prediction of hospital beds during the pandemic. Some are data-driven models as used by Manca et al. for the prediction of ICU beds (6). Others are empirical models, including SIR, SIRD, SEIR and SEIRD, and SIDARTHE (4). A number of models were proposed for estimating hospital bed capacity based on queuing theory. Patient demand for beds was modeled with Poisson distribution with rate λ. The service duration has an exponential distribution $1/\mu$ (5). Further analysis of the model requires parameters like λ and μ. The present study estimates parameters for further analysis of such models.

One approach to decrease the median length of hospital stays is to triage patients based on requirement of specialized care with beds allotted accordingly. The National Institute of Health and Care Excellence (NICE) has published an algorithm to ensure appropriate admissions to the ICU for those most in need (17). In a study of the prediction of length of hospital stay with liver blood test results, liver condition (HBsAb positive, HBcAb positive, and fatty liver disease) was carried out. The median length of hospital stay was 6 days (18). Bhandari mentioned differential neutrophil count and random blood sugar as predictors of mortality risk of COVID-19 (19). One study reported that BMI, age, and CRP were all related to prolongation of length of hospital stay (20). Factors responsible for prolonged LOS in which the median was 11 days (IQR, 5–15 days) showed the most important were lower neutrophil counts, higher partial thrombin time (PT), lower D-Dimer associated with prolonged length of stay at hospital (21). A novel strategy to manage patients is to triage based on disease severity with management of mild patients in shelter homes. The shelter homes are large-scale, temporary hospitals, assembled rapidly by converting existing public places such as stadiums and exhibition centers into healthcare facilities. The important characteristics of shelter homes are rapid construction, large scale, and low cost.

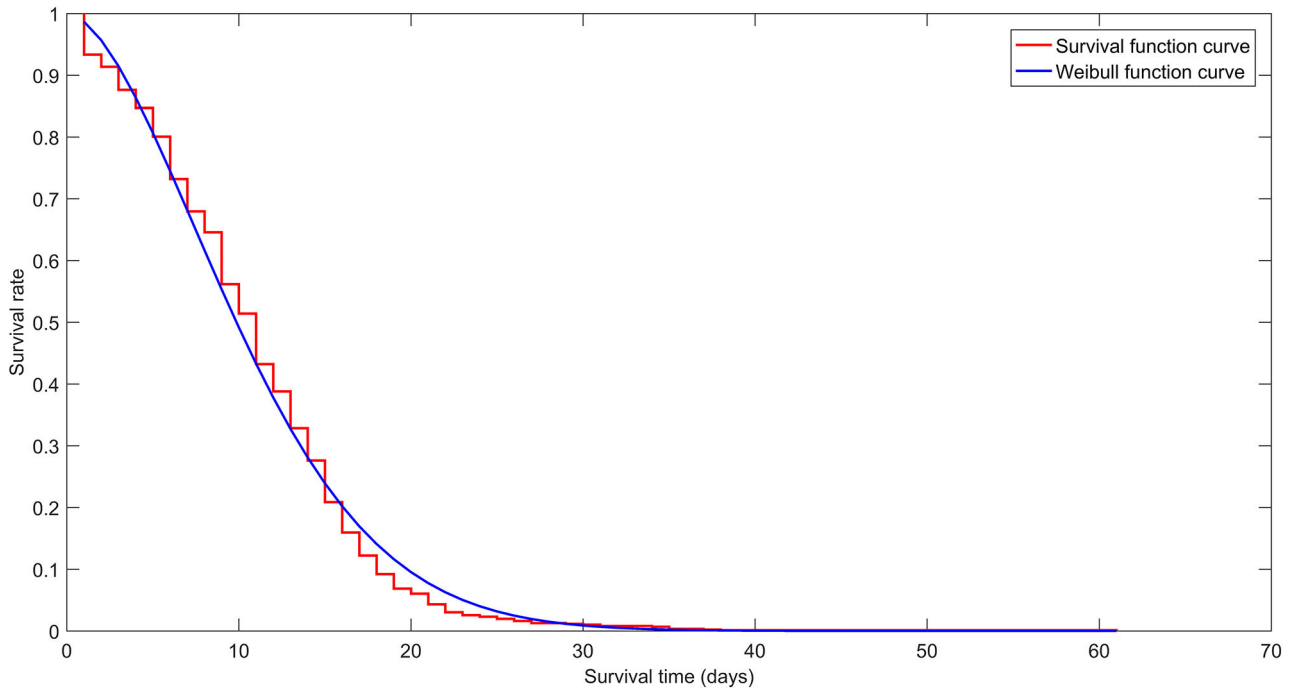

FIGURE 2 | Survival curve (red staircase plot) for Hazard 1 shows Kaplan Meier estimates for all age groups. The Cox model was based on the Weibull function curve (blue line plot).

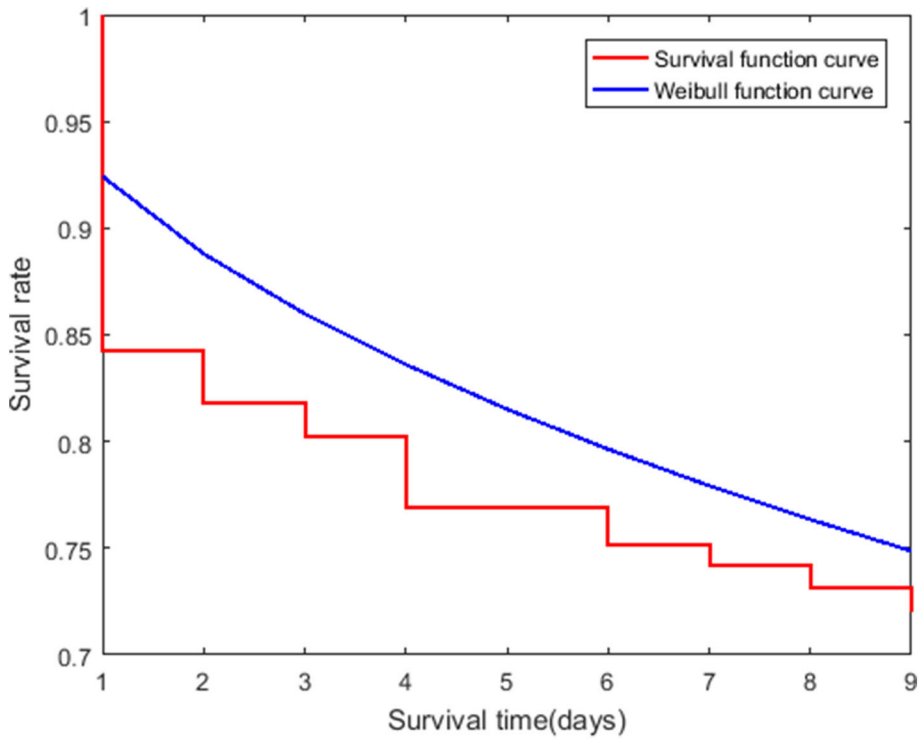

FIGURE 3 | Survival curve (red staircase plot) for Hazard 2 shows Kaplan Meier estimates for patients over 60 years of age. The Cox model was based on the Weibull function curve (blue line plot).

They serve functions of isolation, basic medical care, triage, frequent monitoring and referral, essential living, and social engagement (22).

Finally, the WHO Scientific and Technical Advisory Group for Infectious Hazards (STAG-IH) reviewed available information about COVID-19 and focused on closure monitoring of epidemiology, communication strategies, intensive source control, continued containment activities, intensified active surveillance, resilience of health systems, mitigation activities during community transmission, development of serological tests, and continued research (23).

Conclusion

The present study will help facilitate an evidence-based decision-making process for management of the COVID-19 pandemic. The estimation of dynamic parameters of patient flow in a hospital helps in hospital management. Further, the parameters can be used by various mathematical models to predict future requirements.

Limitations of the Study

The study includes only age and gender as covariates to run the model. The clinical covariates, such as severity, symptoms, and CT scores may provide more precise information about survival time and length of hospital stay.

DATA AVAILABILITY STATEMENT

The data analyzed in this study is subject to the following licenses/restrictions: Data is available on reasonable request to corresponding author. Requests to access these datasets should be directed to Amit Tak, dramittak@gmail.com.

ETHICS STATEMENT

The studies involving human participants were reviewed and approved by Ethics Committee, SMS Medical College, Jaipur (Letter No. 524/MC/EC/2020 dated 7 July 2020). Written informed consent for participation was not provided by the participants' legal guardians/next of kin because: Ethics Committee said, as per the National Ethical Guidelines for Biomedical and Health Research involving Human Participants by Indian Council of Medical Research, 2017 (section 5: Informed Consent Process- Box 5.2, Page No 53 and 54), the study being retrospective where participants have been deidentified, the waiver of informed consent is hereby granted.

AUTHOR CONTRIBUTIONS

SB, AD, and JS provided administrative support, AT, SD, MD, and TW did concept, design, and data analysis and interpretation. AS helped in provision of patients. SK helped in collection and assembly of data. BP, SS, and JG helped in manuscript writing. All authors commented and finally approved the manuscript.

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SUPPLEMENTARY MATERIAL

The Supplementary Material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/fpubh.2020.585850/full#supplementary-material

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Conflict of Interest: The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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REVIEW
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E-Leadership and Teleworking in Times of COVID-19 and Beyond: What We Know and Where Do We Go

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Suddenly, COVID-19 has changed the world and the way people work. Companies had to accelerate something they knew was imminent in the future, but not immediate and extremely humongous. This situation poses a huge challenge for companies to survive and thrive in this complex business environment and for employees, who must adapt to this new way of working. An effective e-leadership, which promotes companies' adaptability, is needed. This study investigates the existing knowledge on teleworking and e-leadership; and analyzes the supposed challenges. The literature review shows that companies with effective e-leadership can view teleworking as an opportunity. It is advantageous for not only companies' productivity but also the environment and people who work remotely. However, a traditional or no leadership can result in some risks. Thriving in remote work environments implies that managers must adjust the companies' structure, making them less hierarchical, and developing new abilities to establish a strong and trustworthy relationship with their employees to maintain their competitiveness, while retaining a genuine concern for their employees' well-being. Similarly, successful e-leadership must be able to consolidate and lead effective virtual teams to accomplish organizational goals. This study contributes to the literature and leaders during the pandemic.

Keywords: e-leadership, teleworking, COVID-19, virtual teams, remote work environments

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INTRODUCTION

In the past few months, telework or working from home has experienced rapid growth owing to the pandemic, leading to significant changes in work methods. İt refers to a flexible working method that is not limited by time, location, type of communication technology, and the use of information. The successful implementation of this requires technology, social, and organizational support specifically in the form of e-leadership practices where the emergence of digital technology and Internet services has facilitated the progress of teleworking. The current pandemic (COVID-19) has generated a massive and sudden change in how companies operate. After the outbreak of

COVID-19, social distancing, which means a deliberate physical space between individuals, has been adopted as a sound prevention method (Prin and Bartels, 2020) and thus necessitated remote working. In this context, information and communication technologies (ICTs) allow employees to work anytime and almost everywhere (Müller and Niessen, 2019). Moreover, teleworking was imminent, but the pandemic has made it a compulsion. It is speculated that this new global work norm would continue even after the pandemic is overcome. This change has deeply impacted not only how organizations operate but also the relationship between employees and employers. Thus, in this new work environment with possible risks (see Bouziri et al., 2020; Lambert et al., 2020), opportunities, and flexible work arrangements, leadership practices cannot be the same. Leadership practices must adapt to new remote or virtual conditions for effective leadership and sustainable performance. This is why Bennis (2009) on his famous book "on becoming a leader" argued that leaders are not born they are made. Leaders should transform themselves to achieve organizational goals by engaging teleworkers who enjoy a fruitful virtual work environment and allow them to thrive in their work. Undoubtedly, leadership in this new labor reality will be decisive for organizations to survive and grow. As nature has demonstrated and this can be applied to companies, if companies do not respond to crises and adapt to the new conditions, they are likely to disappear. Based on a literature review (from 2000 to 2020), this study investigates the existing knowledge about teleworking and e-leadership and pre- and post-COVID-19 risks and opportunities for organizations. Between March and July 2020, we carried out this literature review, looking for scientific publications on telework and e-Leadership in academic journals-databases (Web of Sciences, PsychINFO, SCOPUS, SciELO). The literature search was carried out using the following keywords and combinations between them: Telework, e-leadership, telecommuting and e-leadership, virtual environments, virtual work, virtual teams, telework and COVID-19. Non-recent articles were excluded unless they were quite relevant. The body of the retrieved literature was reviewed and organized for presentation in this document. From more than one hundred articles, we identified and synthesized the findings and contributions of about 80 academic publications, specifically peer-reviewed articles.

The present study revolves around understanding the association between teleworking, leadership and e-leadership that represents the emergence of leadership in the e-environment context where the work is mediated by information technologies, high complexity and a changing working environment that makes imperative for leaders to change their practices, attitude, and behavior for long term organizational sustainability. In order to better comprehend the above phenomena, this study is structured as follows. In section "Teleworking and the Emergence of COVID-19," we discuss the opportunities and risks with teleworking with the emergence of COVID-19. Section "Management, Leadership and Telework Environments" deals with understanding the management and leadership in the environment of teleworking. In section "E-leadership and its Conceptualization," we discuss the phenomenon of e-leadership and its conceptualization. In section "E-leadership, Teleworking and Virtual Teams," the association among e-leadership, teleworking and virtual teams is analyzed. Finally, in section "Conclusion and Propositions for Further Studies," we put forth some propositions for further studies.

TELEWORKING AND THE EMERGENCE OF COVID-19

In the past decades, companies have evolved according to new conditions of the work environment, such as globalization, fierce competition, new demographic structures, and increasing development of ICTs (Wojcak et al., 2016). The transition from the industrial era to a digitalized business environment led to a shift from a mechanistic perspective to a more organic perspective, where organizations embrace flexible structures (Pulley and Sessa, 2001). After 2000s, work has been increasingly detached from on-site (Felstead and Henseke, 2017) to facilitate the workforce and to provide better services to the customers. Therefore, teleworking was steadily growing globally in several sectors. Among these sectors, service industry encompasses the highest overall percentage of workforce who work remotely (17%), followed by health care industry (12%), finances and insurance industry (10%), manufacturing sector (8.5%), and education industry (7.5%) (He et al., 2020). Teleworking is always debated because of the blurring boundaries regarding non-work and work, personal, and social effects of not being physically present at a job, and the risks and benefits of flexible working hours. Under traditional conditions (e.g., before COVID-19), teleworking was needed temporarily (Allen et al., 2015). However, in this current pandemic situation, most of the employees around the world are full time away from the office and working from home. Thus, this pandemic has suddenly changed how people work and it is not yet very clear how long we have to continue working from home in different countries.

The World Health Organization (WHO) officially announced the outbreak of coronavirus disease on March 11, 2020, as a pandemic and suggested preventive measures to contain its spread. Telework was an important measure suggested by World Health Organization (2020) and successfully implemented by organizations and governments around the world. Thus, since March 2020, more than 3.5 billion individuals have been confined to their homes, which meant that several millions were teleworking (Bouziri et al., 2020). This teleworking may lead to social or professional isolation, which is referred to as the missing of the everyday social aspect of work because employees are physically away from other workmates, hence leading to not being actively participating in information sharing and co-learning. This feeling of professional isolation adversely affects job performance (Golden et al., 2008) because employees do not have their supervisor and colleagues' support in problem solving as they would if they were physically present at work. In this context, the role of e-leadership lies in facilitating the work conditions and keeping employees motivated toward achieving the desired goals. This situation calls for a different type of leadership, known as e-leadership, which entails the development

of distinct abilities to improve organizational functioning in virtual and remote work environments (Roman et al., 2019).

Before the COVID-19, teleworking was steadily growing globally across many sectors. The pandemic accelerated this process and now companies must operate with employees having to work in places different from the traditional workplace through teleworking. In fact, teleworking was popular even before the pandemic (He et al., 2020) and the infrastructure for teleworking already existed. Hence, the adoption of this working style has been relatively easy for several companies (Béland et al., 2020). Tietze and Musson (2005) asserted that the future of work will be "flexible, mobile, temporary and mediated by technology" (p. 1331), that is, by teleworking. Telework, telecommuting, or working remotely is a wide-ranging concept that covers any paid work performed from a distance in any place different from the physical presence in the organization where employees meet organizational objectives through ICTs, sometimes managing their own time under less direct supervision (Wojcak et al., 2016). These employees usually work remotely with autonomy for at least a few days of their labor time (Nayani et al., 2018). However, Bentley (2014) highlighted the importance of delimiting the notion of telework to avoid confusion with employees who work for companies from outside, such as those who work in call centers or as freelance employees.

Opportunities of Teleworking

Teleworking has some potential advantages. Empirical studies have found favorable outcomes of teleworking such as job performance, job satisfaction, lesser work-family imbalance, reduced rates of stress, and lesser turnover intentions (Kossek et al., 2006; Fonner and Roloff, 2010; Coenen and Kok, 2014; Vega et al., 2015). Likewise, Othman et al. (2009) demonstrated the positive effect of teleworking on employees' work-life balance. Additionally, Azarbouyeh and Naini (2014) stated that teleworking is effective in enhancing the quality of life, whereas, Kazekami (2020) found that teleworking improves employees' happiness and work satisfaction. However, the benefits are evident where the employees find managerial, peer, and technological support. This support helps reduce any potential negative impacts arising from social isolation, mitigate the work-family conflict, and reduce the stress (Bentley, 2014).

Teleworking can also influence on the reputation and corporate image because green companies are concerned about the environment. Currently, heavy traffic and air contamination are some of the most relevant global issues (Giovanis, 2018). Teleworking is a viable short and long-term solution to improve the quality of air mainly in urban areas while improving the quality of life (Giovanis, 2018). Consequently, the world will witness less contamination because employees do not have to use daily transport, thus saving time and money. Interestingly, the term "telecommuting" was used for the first time in the 1970s to relieve traffic and reduce pollution through flexible and better work-life balance (Nilles, 1998). Another advantage of a highly complex work environment is that companies have access to specialized expertise, regardless of the team members' location, which allows companies to find more creative solutions to this complex global work environment (Malhotra et al., 2007). Similarly, digitalization, new communication tools, and more availability and speed of information increase the efficiency and process of standardization (Cortellazzo et al., 2019). For employees, teleworking offers more flexibility to deal with family matters because they can work anywhere and anytime, thus improving the family atmosphere (Fedakova and Ištoňová, 2017), and the autonomy to manage time allows them to harmonize their personal and work duties (Wojcak et al., 2016). Hence, it increases job opportunities for women and employees with disability (Morgan, 2004).

Furthermore, work autonomy through free choice to directly influence one's working time, place, and methods is associated with higher productivity (Pavlova, 2019). Moreover, in their meta-analysis of 46 studies Gajendran and Harrison (2007) showed that telecommuting lowers turnover intentions and stress. The absence of an immediate supervisor and a less formal working atmosphere reduces the work stress for employees. Moreover, teleworking helps employees create their own rhythm of work and prevents distractions from other employees (Kłopotek, 2017). Additionally, it decreases the individual and organizational burdens of absenteeism because it allows employees to fulfill their work obligations even in times when there is trouble reaching the office, allowing employees to fulfill their duties (Nakrošienė et al., 2019). Indeed, these advantages contribute to greater organizational commitment, job satisfaction, and well-being.

Risks of Teleworking

Some risks posed by teleworking must be considered, namely, social isolation from work teams (Pyoria, 2011). Social isolation leads to employees being disconnected from the working environment leading to lower performance and gradual demotivation (Wojcak et al., 2016; Fedakova and Ištoňová, 2017). Long-term isolation has adverse effects on employees' performance and increases turnover intention, family-work and work-family conflict (Golden et al., 2008). In work-to-family conflict individuals are hindered to meet role demands in their private life because of work demands while in the family-to-work conflict, they can be hindered to meet their private roles because of home demands. Their study also empirically revealed that volition, perceived work pressure and perceived home pressure are all relevant for understanding employees' work-to-home conflict rather than home-to-work conflict and work-home practices to be beneficial employees should not feel pressure to either use or not use offered practices (Delanoeije and Verbruggen, 2019). Furthermore, as Cooper and Kurland (2002) indicate teleworking reduces the learning benefits that people enjoy when working in the same workplace. Moreover, teleworking requires greater organizational skills (Kłopotek, 2017); it is suitable for only self-organized people who are successful in time allocation. On the one hand, teleworking can lead to anxiety among employees about the possible shrinking of career prospects owing to reduced visibility (Maruyama and Tietze, 2012), and unfortunately the advantages of teleworking come at the cost of intensified work. Therefore, a commonly cited concern of managers regarding teleworking is the possibility of decreased job performance. In other words, the lack of trust in

employees' ability and willingness to perform at the same level compared with what they could attain if they were to work with their manager in the same place (Kaplan et al., 2018). Digital environments have some common problems, such as email/data overload, employees' alienation, weak social relationships, poor accountability in teams, low trust, insufficient technological skills, and an inability to influence change based on commitment (Van Wart et al., 2019).

Finally, telework raise ethical concerns for e-leaders, such as exploitation of employees with work and information overload that overlap with domestic and work settings, resulting in an intrusion into employees' personal life (Cortellazzo et al., 2019; Gálvez et al., 2020). Although teleworking gives individuals greater autonomy in terms of time and space, the simultaneous use of different normative control mechanisms under the guise of autonomy leads to work intensification and extra burden to employees. This obscure control mechanism results in greater self-regulation and promotes greater work efforts from employees (Bathini and Kandathil, 2019). Moreover, individuals who are grateful for the flexibility provided by teleworking make greater effort and achieve higher performance, ending up with a higher sacrifice than with traditional working methods (Putnam et al., 2014). **Table 1** shows the main reported findings of opportunities and risks of teleworking.

MANAGEMENT, LEADERSHIP AND TELEWORK ENVIRONMENTS

Leadership has several definitions; however, generally leadership can be defined as an influence process to achieve organizational goals. In the traditional work environment, this influence is exerted by not only formal leaders but also employees without formal authority (informal leadership). In teleworking, the influence of formal leaders is more obvious. They must influence to build effective and functional virtual teams to reach organizational goals. Before analyzing the concept of leadership in virtual environments, this study makes the following propositions supported in the literature on leadership: (1) there is no leader without followers; (2) one can be considered a leader only when people recognize him or her as such; (3) leadership can be considered an interactive process of social influence and it is based on relationships; and (4) as a result of effective leadership, employees make their best effort to accomplish organizational goals. Hence, in addition to the formal authority, leaders must develop the ability to influence others to get work done.

Beyond the polemic and the unfinished debate about whether leadership and management should be conceived as the same construct (Mintzberg, 2009) or distinct (Kotterman, 2006), in teleworking the role between one and the other appears more distinct than in traditional workplaces. Teleworking brings more challenges for leaders than managers. In other words, teleworking is more feasible and even improves the efficiency of the traditional role of management (i.e., planning, budgeting, control and establishing administrative procedures) than exerting effective leadership (i.e., influence others to achieve organizational goals) through electronic devices. According to Nayani et al. (2018), both leadership and management are equally important in teleworking. However, adapting traditional leadership practices to a technologically mediated environment is more complicated (Pulley and Sessa, 2001). A distributed workforce must be led by adopting new and more complex methods in communication, performance management, training, and relationship building (Flood, 2019).

From the management perspective, teleworking can be favored by flatter and more decentralized structures (Cortellazzo et al., 2019). The increase in connectivity within the companies in addition to information availability contributes to diminishing hierarchies and organizational boundaries, leading to companies working by projects more than traditional activities and thus, employees participate in the creation of value for the companies (Cortellazzo et al., 2019). Owing to information availability, the power of the company tends to be more distributed and less centralized, involving employees in the decision-making process. This participative decision-making helps leaders analyze and prioritize relevant information from the large amount of available data, respond faster and more innovatively for better decision making (Cortellazzo et al., 2019). Darics (2020) highlighted that in a remote work environment, management and leadership functions are combined and managers must manage performance and implement solutions when needed and create and maintain a team identity by establishing and sharing a vision, corporate values, and organizational goals into a trusting working environment. Moreover, in teleworking, considering a reduction in the social and interpersonal distance, leaders should be more democratic with access to information and willing to keep an open communication (Montgomery et al., 2016). In this context, the adaptive structuration theory (DeSanctis and Poole, 1994) suggests that many organizational phenomena including organizational leadership transform when interacting with Advanced Information Technologies (AITs). From this approach, AITs mediate leadership influence and create an integrated mechanism of leadership and management. In fact, from a management perspective, AITs can have various purposes, including sharing information, planning, record keeping, or data analysis. From a leadership perspective, effective leaders at e-leadership positions are successful when they can use various AITs to achieve greater performance, enhance employees' job satisfaction while reducing the rates of turnover (Montgomery et al., 2016).

E-LEADERSHIP AND ITS CONCEPTUALIZATION

Electronic or e-leadership is not just an extension of traditional leadership but also implies a crucial change in how leaders and followers relate to each other within the organizations and with stakeholders (Avolio and Kahai, 2003), making it imperative for leaders to change their practices (Malhotra et al., 2007). Kahai et al. (2013) asserted that scholars should go beyond traditional leadership theories to explain the role of leaders and leadership in remote work environments. E-leadership implies

TABLE 1 | Opportunities and risks of teleworking.

Opportunities	Source	Risks	Sources
Offers job opportunities for people with disabilities and for women increases job opportunities for women and employees with disability.	Morgan, 2004	Reduction of the learning benefits that is available when people are working in the same workplace.	Cooper and Kurland, 2002
Global workforce available, access to a specialized knowledge regardless of geographic location.	Malhotra et al., 2007	Social and professional isolation.	Cooper and Kurland, 2002; Golden et al., 2008; Pyoria, 2011; Bentley, 2014
Greater competitiveness to successfully insert in global work environments.	Avolio et al., 2014; Narayanan et al., 2017	Employees concerns due to the reduction of career prospects by feeling less visible.	Maruyama and Tietze, 2012
Lower stress, lesser turnover intentions, lesser work-family imbalance and job satisfaction.	Kossek et al., 2006; Gajendran and Harrison, 2007; Fonner and Roloff, 2010; Coenen and Kok, 2014; Vega et al., 2015	Because the flexibility, highly motivated employees can work more hours than in traditional work environment, resulting in exhaustion.	Putnam et al., 2014
Autonomy and flexibility at work allow harmonizing the personal and work matters favoring the workers' well-being.	Fedakova and Ištoňová, 2017	Physical distance and cultural diversity threaten trust building, commitment and cohesion among the team members.	Hoch and Kozlowski, 2014
Information availability increases job performance.	Schwarzmüller et al., 2018	Lower job performance and demotivation.	Golden et al., 2008; Wojcak et al., 2016; Fedakova and Ištoňová, 2017
Contribute to the solution of global problems such as pollution and air quality, while influencing the firms' reputation.	Giovanis, 2018	Work-home conflicts.	Golden et al., 2008; Bentley, 2014; Delanoeije and Verbruggen, 2019
The team members' heterogeneity promotes creativity and innovation through a combination of various perspectives to achieve an objective.	Gupta and Pathak, 2018	Work and information overload that overlap with domestic and work settings.	Cortellazzo et al., 2019; Gálvez et al., 2020
Decreases absenteeism due to employees do not have to face difficulties to reach the workplace.	Nakrošienė et al., 2019		
Opportunity to interact and establish effective virtual teams, increasing their creative capacity.	Malhotra et al., 2007; Schwarzmüller et al., 2018; Cortellazzo et al., 2019		
Work autonomy and less distraction potentially allow higher productivity.	Kłopotek, 2017; Pavlova, 2019		

Source: Authors own elaboration.

the development of distinct abilities to improve organizational functioning in virtual work environments (Roman et al., 2019). For e-leaders, the known social skills, such as the characteristics of effective face-to-face communication may not be enough to lead in virtual environments, where these characteristics must be complemented with the skills to manage various virtual communications platforms. However, Liu et al. (2020) asserted that many propositions used in generic leadership theories can be applied to e-leadership. This premise should be tested to build a genuine theory of e-leadership. Dulebohn and Hoch (2017) highlighted the need for developing a new theory and conducting empirical research to help organizations in designing, structuring, and managing virtual teams.

Cortellazzo et al. (2019) state that there is no shared approach to study and theorize about this phenomenon. However, because e-leadership is a multidimensional phenomenon, it should be studied from different disciplines, avoiding fragmented knowledge, and from different levels of analysis: macro (e-leadership and organization) and micro (e-leader's skills and leading virtual teams). Thus, as asserted by Liu et al. (2020), e-leadership is an important trend not only for the rapid progress in technology and its application during the pandemic but also presents a challenge for companies to adopt the technology, that is, to benefit from its advantages. These authors stated that if this process is not well addressed by leaders and used only to impose mandates, e-leadership could increase alienation and chaos. Up to now, hybrid teleworking (work from home few days a week) appears to provide the best balance between remote work flexibility and benefits of working face to face with management and coworkers. However, more evidence is needed (Bentley, 2014). Supporting this view, a study conducted in Australia on teleworking, productivity results showed that employees preferred a maximum of 1–3 days away from the office as the most feasible telework arrangement (Bosua et al., 2017).

Some years ago, e-leadership was described as an ineludible challenge for companies (Esguerra and Contreras, 2016). The "quiet revolution," as named by Avolio and Kahai (2003), occurred to companies much earlier. Being prepared for virtual work environments was a priority to respond to a globalized world immersed in the digital era. Now during the pandemic

and onward, it is crucial for business survival. Thus, e-leadership will be a relevant challenge that companies must face for success and sustainability. E-leadership is an irreversible trend that is here to stay.

Leadership as a field of study has largely focused on organizations where employees are working on site. Studies on leadership and teleworkers are scarce. Avolio et al. (2014) stated that the study of e-leadership is in the early stage of development. Van Wart et al. (2019) asserted that the study on how the current digital revolution is changing the relationship between leaders and followers has been modest. Interestingly, though, from 2001 to date, there are 102 published articles related to e-leadership in the Web of Science Core Collection. Of these, only 32 papers included the term e-leadership in their title. In their seminal work, Avolio et al. (2000) defined e-leadership "as a social influence process mediated by AIT to produce a change in attitudes, feelings, thinking, behavior, and/or performance with individuals, groups, and/or organizations" (p.617). Similarly, Al-jedaibi (2001) explained e-leadership as the kind of leadership in the e-environment context where work is mediated by information technologies, especially the Internet. However, the leader is not necessarily a "tech guru." He or she only should know how to benefit from high technology and lead efficiently through technology. Gurr (2004) also focused on e-leadership and claimed that technology-mediated environments require unique leaders who are good at coping with complexity. They should establish a suitable social climate with sustained communication and can demonstrate exemplary interpersonal skills through related technology. Recently, Cortellazzo et al. (2019) stated that in spite of the advances, there is no well-established and consensual definition of e-leadership.

Cowan (2014) proposed that effective e-leadership should be characterized by building trust with each member of the team and establishing a virtual "presence" preventing distance from becoming a barrier. Similarly, e-leaders should address the teams' social-emotional needs and their members and promote healthy teams through interactions. E-leaders should develop effective communication skills, that is, select a suitable communication tool, provide relevant and contextual communication considering possible cultural differences, provide positive feedback to the teams, and recognize their performance. Nayani et al. (2018) asserted that besides high levels of instrumental support and competent communication, leaders should promote trust using motivational language. More recently, Roman et al. (2019) asserted that effective e-leaders should communicate clearly, promote adequate social interactions, know how to use the technological media, be able to build responsible teams, inspire change, and develop trust virtually. Van Wart et al. (2019) defined e-leadership as ". . .the effective use and blending electronic and traditional methods of communication. It implies an awareness of current ICTs, selective adoption of new ICTs for oneself and the organization, and technical competence in using those ICTs selected." (p.83). According to the authors, effective e-leadership is not only use of ICTs but also implies that when this media offers the best advantages, select the most appropriate one, based on the needs, using face-to-face communication channels where more appropriate, integrating distance and non-distance methods, according to the purposes.

Van Wart et al. (2019) conceptualized e-leadership as the effective use and blending of electronic and traditional methods of communication and proposed the definition of e-leadership through the following competencies that should be empirically tested: (1) Communication skills (communication clarity, avoidance of miscommunication, management of communication flow), (2) Social skills (leaders' support), (3) Team building skills (encompassing team motivation, team accountability, and team member recognition), (4) Change management skill (covering change techniques), (5) Technological skills (correct use of relevant ICTs, blending traditional and virtual methods, technological knowledge, and technological security) and (6) Trustworthiness (sense of trust, honesty, consistency, follow-through, fairness, integrity, work-life balance, and support of diversity).

In virtual or remote work environments, leaders should demonstrate a more inclusive leadership style (Schwarzmüller et al., 2018). For e-leaders, the social skills, such as the characteristics of effective face-to-face communication, may not suffice to lead in virtual environments (Roman et al., 2019). Cortellazzo et al. (2019) highlighted that e-leaders should develop a communication where employees feel free to present their ideas, allowing them to participate in the decision-making process and encourage autonomy, collaboration, and responsibility, and promoting a positive organizational environment with their leadership. In this new work environment, information is more visible and easier to share, allowing employees to be more independent in their work. Thus, companies not only benefit from employees' good performance but reduce the need to supervise them (Schwarzmüller et al., 2018).

In this regard, Roman et al. (2019) defined e-communication as the ability to communicate properly through ICTs, avoiding errors or excesses that affect good performance. This ability is marked by the use of an appropriate tone, providing clear messages to employees through the right communication media. These authors also suggested that this process involves technical issues, such as selecting the best method to communicate considering the richness of the tool, the receiver's preferences, and decide upon the use of synchronous or asynchronous methods. With regard to the use of synchronous or asynchronous methods, both temporary forms of communication offer advantages. For example, asynchronous communication allows a continuous flow of information (Gupta and Pathak, 2018). Additionally, Cortellazzo et al. (2019) highlighted the importance of maintaining clear norms of communication, having regular interaction with the teams, providing positive feedback, avoiding ambiguous messages, and conducting good supervision of each member's contribution. In contrast, deficient communication from leaders may lead to unknown situations, leaving employees with a feeling of helplessness (Wojcak et al., 2016). The e-social environment is the second important property of e-leadership (Roman et al., 2019), that is, creating a positive work atmosphere with a sense of connectedness with the group to increase communication and collaboration through digital

communication methods. Through e-social characteristics of e-leadership, isolation among team members can be successfully prevented (Walther and Bazarova, 2008). Furthermore, the e-change property refers to the e-leaders' capability of making noteworthy changes required for adaptation of AITs. While the e-team property of e-leadership is about a leader's capabilities in creating accountable, satisfied, and efficient teams in virtual business environments, e-technological skills are also important e-leadership properties. It is the competency of an e-leader to be aware of novel technologies, being able to keep up with relevant technological developments, and embracing high-level cyber security (Roman et al., 2019).

Finally, another important characteristic of e-leadership is the capacity to innovate. E-leaders should be able to identify the need for change and promote innovation in their organizations and teams (Schwarzmüller et al., 2018). However, e-leaders must be careful that these continuous changes do not disrupt the company's focus and its mission. Therefore, these leaders should be flexible, innovative, have clarity about the organization's goals (Cortellazzo et al., 2019). **Table 2** presents the main issues related to e-leadership.

E-LEADERSHIP, TELEWORKING AND VIRTUAL TEAMS

As mentioned before, teleworking is a new form of work organization that gained ground in most organizations around the world due to the pandemic, increasing distance in the interpersonal relations in the work environment. This way of working offers huge opportunities to companies, but a huge challenge to leaders who have to lead an environment of boundaryless work through technology. This challenge implies that both leaders and followers develop technical competencies to facilitate the monitoring, coordination, and alignment of work through novel technology-supported structures, in order to diminish barriers (Alfehaid and Mohamed, 2019). For this purpose, e-leaders have to be competent with the latest ICTs (Groysberg, 2014) E-leaders not only have the responsibility to adopt internet-based computer technologies in their organizations but also have to create awareness regarding these technologies to make teleworking possible and convenient (Van Wart et al., 2019).

TABLE 2 | Main issues about e-leadership.

Main issues
E-leadership is not an extension of traditional leadership (Avolio and Kahai, 2003).
It is a priority to build and share a genuine theory of e-leadership (Dulebohn and Hoch, 2017).
There is no well-established and consensual definition of e-leadership (Cortellazzo et al., 2019).
E-leadership has to be studied from different disciplines (Cortellazzo et al., 2019).
Studies on e-Leadership are still scarce, the knowledge of this topic is in an early stage of development (Avolio et al., 2014; Van Wart et al., 2019).
Some characteristics of generic leadership theories could be applied to e-leadership (Liu et al., 2020).

To take advantage of the possibilities that teleworking offers, companies cannot be led in the same way as has been done traditionally. De Vries et al. (2019) indicates that hierarchical forms of leadership are less suitable in virtual work environments. Traditional leadership is supported in social influence mechanisms. However, in virtual environments this influence is mediated by computer technologies producing changes in behaviors, emotions, thoughts, and performance of workers (Van Wart et al., 2019). In remote work settings, e-leaders cannot be oriented to organize fragmented tasks; they have to be close to their employees reducing the negative impact that produces the physical and psychological distances (Stokols et al., 2009). Similarly, Maciel et al. (2017) stated that effective e-leadership encourages the performance in teleworking by minimizing the distance between the organization and its employees and brings the organization and its customers closer with the help of high technology. To reach that, e-leaders have to develop trust in their relationships, allowing greater exchange of ideas; they encourage information flow, and generate creative solutions (Avolio et al., 2014). Likewise, findings of Panteli et al. (2019) showed that e-leaders boost employees' work engagement through effective use of resources and their attitude of development, support, and nourishment. These properties are helpful in contexts characterized by greater geographic distance, diversity, some ambiguity, and unfamiliarity with remote working. Moreover, through the delegation and the effective provision of feedback, e-leaders develop and support their spatially dispersed and sometimes, socially distanced employees. As Kahai et al. (2013) suggest e-leaders with their behaviors can relieve the potential problems of teleworking such as the greater physical and social distance that makes social interactions difficult. Even though in the related literature most of the researchers are focused on the importance of e-leaders to provide emotional and technological support to their employees (Friedman and Westring, 2015; Bentley et al., 2016), some noteworthy studies are focused on the need to provide ergonomics support to the employee's home office which, in turn, has been related to talent retention of teleworkers (Eversole et al., 2012; Allen et al., 2015).

Virtual team is an attendant concept of e-leadership (DasGupta, 2011). An important challenge for e-leaders is to build effective, autonomous, interdependent (Cortellazzo et al., 2019), and committed virtual teams (Politis, 2014) for which trust is crucial. Virtual teams include members who are geographically dispersed but working together in an interdependent task through electronic means with low face-to-face interaction (Malhotra et al., 2007). Diverse virtual teams have the challenge of coordinating tasks across different locations, time zones, and cultures (Siebdrat et al., 2014). In fact, managing a distributed workforce creates heightened leadership challenges (Hoegl and Muethel, 2016). The inclusion of digital media in the companies, affects their design of work and the way employees work together in effective virtual teams (Schwarzmüller et al., 2018). Because of the pandemic, e-leadership is required more than face-to-face leadership. However, in the future, virtual teams would persist due to the opportunities they offer. Regardless of the leadership style, similar to in person, leaders of virtual teams

should articulate and communicate the vision with passion, shaping a culture based on organizational values; however, the method is still unclear. Even in developed countries, there is a lack of knowledge of e-leadership skills needed to address successful virtual teams in complex work processes (Liu et al., 2020). Thus, how e-leaders can build effective virtual teams is a relevant challenge to the leadership field.

Leading virtual teams effectively offer enormous competitive advantages for the companies. The possibility of building effective teams consisting of people with different experiences, from diverse cultures and knowledge of different fields, regardless of the time and distance, is enormous. Nayani et al. (2018) explained that although distributed workers are diverse, they share common work characteristics of temporospatial distance from coworkers, managers, and leaders. A virtual environment provides opportunities to interact and establish connections with people around the world (Cortellazzo et al., 2019). Malhotra et al. (2007) claimed that this possibility allows thinking globally and acting locally, showing the creative capacity of such a virtual team. However, because the national culture impacts leadership (Dorfman and House, 2004), the geographical dispersion and cultural diversity between team members can be a barrier to building trust within the teams (Gupta and Pathak, 2018). Indeed, the physical distance and cultural diversity threaten trust building among the team members, affecting their commitment and cohesion (Hoch and Kozlowski, 2014). In this regard, e-leaders should develop intercultural competences to communicate adequately with team members and build trust through interrelationship. A virtual team leader should develop cross-cultural skills to understand different cultures, their similarities, and differences (Schwarzmüller et al., 2018). Nevertheless, there is a need for further research on the impact of culture on e-leadership (Cowan, 2014). Under effective e-leadership, such diversity in the teams increases the members' innovative behavior and will influence the companies' innovation. In this regard, more than traditional leaders, e-leaders should lead diversity if they must leverage the advantage offered by virtual teams. In this regard, Gupta and Pathak (2018) asserted that team members' heterogeneity promotes creativity and innovation through a combination of various perspectives to achieve an objective. Another important challenge for e-leaders is to recruit, retain, reward, and motivate globally talented employees to maintain their competitive advantage in the globalized world (Avolio et al., 2014).

Similar to traditional teams, leading a virtual team requires leadership and management skills. As Nayani et al. (2018) asserted, organizations should ensure occupational safety and health of teleworkers through appropriate management (i.e., systems, procedures, and practices) and effective leadership practices. However, there is a paucity of research in this field and its results are fragmented. Leading virtual teams has an additional challenge because leaders should ensure that each team member is committed to the project and gives the best according to his or her expertise (Malhotra et al., 2007). Recently, Schwarzmüller et al. (2018) highlighted that e-leaders should develop tolerance to the ambiguity and be creative in establishing the organizational structures and processes that assure that all members of virtual teams are working for the shared objective. Supporting this view, Darics (2020) claimed that e-leaders have two important roles: (1) managing performance and implementing novel solutions to work-related problems, and (2) creating and maintaining group identity by establishing a shared mission, vision, values, and goals. Thus, Malhotra et al. (2007) proposed six leadership practices to have successful virtual teams: (1) establish and maintain the thrust through technology; (2) appreciate and understand the diversity; (3) manage the work-life cycle well through meetings; (4) monitor progress of teamwork; (5) enhance the visibility of the team members (within and outside of the team), and (6) allow individual members to avail of the benefits from the teamwork.

Jones and O'shea (2004) stated that the hierarchical leadership approaches in e-teams have limitations in terms of providing flexibility to group members during the process of collaboration. In virtual environments, e-leaders should distribute the leadership well within the teams. This allows teams to shape their own leadership style and promote the collective development of leadership (Gupta and Pathak, 2018). However, sharing leadership does not exclude the formal leader figure but assumes that any member can lead the team, follow up, and make the best decision for the team (Cortellazzo et al., 2019). Through shared leadership, not just the team leader but also team members take responsibility and assume authority to consider both their own spheres of work and the entire project (Hoegl and Muethel, 2016). Shared leadership promotes team members' identification within the group and initiates action flows for goal achievement. However, for shared leadership, the leader should realize and appreciate members' potential and willingness to assume the responsibility of a few leadership duties (Hoegl and Muethel, 2016). Finally, communication in virtual teams is more complex than in traditional teams that use face-to-face communication. In most virtual teams, e-leaders should communicate and work asynchronously through AITs. Hence, time and space separation in virtual teams create important challenges for leaders by demanding extra leadership competencies in ensuring and promoting organizational management (Fan et al., 2014). Given that the coordination of virtual teams for task accomplishment, responsibility, and knowledge sharing is done through telecommunication technologies, sometimes there may be distortion in information interpretation leading to misunderstandings and employee demotivation. Thus, e-leaders should be highly competent in their verbal communications to motivate their employees (Fan et al., 2014). Virtual team leaders should avoid employees' feeling of isolation and promote team cohesion. This implies adequate establishment of norms of collaboration, knowledge sharing, recognition, and rewarding the teams and their members (Malhotra et al., 2007) to be "present" socially and emotionally (Cowan, 2014).

CONCLUSION AND PROPOSITIONS FOR FURTHER STUDIES

The pandemic has increased the need to augment our knowledge on how to lead effectively and build highly functional virtual teams. Despite being recognized much earlier, there is limited

knowledge on e-leadership and no theory specific to such leadership. It is unclear whether the current knowledge on leadership can be applied to e-leadership. Similarly, results from various studies on the effectiveness of e-leadership and its effects on employees have been inconclusive. There is some consensus that leaders should consider giving the opportunity to some employees to telework when the job or the task can be done out of the workplace and to avail of the benefits of this mode of work. Thus, as a result of applied research, it is imperative to create profiles of eligibility to telework. In other words, people who can leverage the advantage of working remotely must establish different levels of attendance based on the work or task (e.g., once a week, some days a week, or full-time).

The revised literature highlighted the importance of achieving a better understanding of the effects of teleworking on employees' well-being and organizational performance. Currently, due to the pandemic, there is a huge global interest in studying this topic from the perspective of both practitioners and researchers. It is needed to conduct studies that rigorously examined teleworking and e-leadership and the reasons for success and even for the failures to learn more about how to manage this new way to work. However, there is a paucity of knowledge on the outcomes of such a method of work, and its results have been inconclusive. For example, Narayanan et al. (2017) mentioned that companies such as Hewlett-Packard, Yahoo, and Best Buy reduced the hours of teleworking and asked workers to return to the traditional workplace. Case studies are needed to understand these failed experiences.

Finally, one of the main weaknesses in the studies of teleworking and e-leadership is their methodology, small samples are not representative, and robust theoretical foundations are scarce. It is important to improve methodological rigor for acquiring reliable and valid data. More than descriptive or correlational studies are necessary. More experimental and quasi-experimental studies are needed as well as more longitudinal studies and mixed methods for better comprehension of the phenomena.

Due to the availability of a global workforce, it is important to conduct cross-cultural studies and analyze the role of e-leadership and cultural differences. As Narayanan et al. (2017) suggested, research should be conducted on psychology and sociology and topics such as social isolation, group, and team behavior and management practices in teleworking. How to promote trust through organizational culture and leadership should be examined. At the individual level, research on psychology should be conducted to understand the personality, qualities, skills, and cognitive needs of those employees who are more suitable to work remotely and conduct financial research for the cost-benefit analysis of teleworking. Liu et al. (2020) and Cortellazzo et al. (2019) suggested that a theory of e-leadership, sharing approaches, and theorizing about this phenomenon is needed. Finally, based on Nayani et al. (2018), the teleworkers' health is another promising line of research that should be developed through robust conceptual frameworks and rigorous methods.

In sum, from the theoretical perspective, further studies should help to build a theory of e-leadership that is common for all researchers in this topic. In this way, findings around the world can be contrasted, which will contribute to building a solid body of knowledge of how to lead in virtual environments. These studies will help also e-leaders to develop their intercultural competencies to lead in global environments. Likewise, the methodology of empirical studies should be strengthened to conduct research in controlled settings (research in a laboratory) making relevant contributions that explain how to successfully lead in virtual environments. In fact, the body of knowledge that will continue to be built in the next years will allow to identify and test the competencies that need to be developed by e-leaders in order to be effective as leaders and efficient as managers in this new way of work, which apparently will be kept to varying degrees once the pandemic is overcome. As a result of these studies, leaders can be trained and human resource managers can be guided in order to increase organizational performance while improving the employees' well-being in a healthy work environment.

AUTHOR CONTRIBUTIONS

FC was engaged in the investigation, literature search and selection, writing original draft, preparation, and finishing the last version. EB was involved in investigation, literature search and selection, contribution to the original draft, and contribution to the last version. GA was engaged in investigation, literature search and selection, contribution to the original draft, and contribution to the last version. All authors contributed to the article and approved the submitted version.

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Conflict of Interest: The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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Impact of the Healthcare System, Macro Indicator, General Mandatory Quarantine, and Mask Obligation on COVID-19 Cases and Death in Six Latin American Countries: An Interrupted Time Series Study

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Background: Different coping strategies have been implemented by various governments worldwide to address the emerging health crisis of COVID-19. While most developed countries count on supporting healthcare and social systems, developing countries face additional challenges due to low macro indicators. The implementation of measurements such as quarantine are shown to be successful to flatten the curve of infection and death. In this context, it is important to test whether those measurements have an impact on the distribution of cases of COVID-19 in developing countries that face additional challenges such as lack of social security due to informal employment. A country comparison for Colombia, Costa Rica, Peru, Ecuador, Mexico, and Chile has therefore been conducted.

Method: The healthcare systems and macro indicator as well as the distribution of death due to COVID-19 per thousand inhabitants are compared descriptively. Using Multiple Interrupted Time Series Analysis with synthetic control units the impact of the General Mandatory Quarantine in Colombia, Peru, and Ecuador as well as the impact of Mask Obligation in public in Colombia and Chile have been tested.

Results: No clear impact of the poverty headcount ratio at the national poverty line and urban population on the percentage of death within the confirmed cases has been found. The out-of-pocked spending within health expenditure as a barrier in access to healthcare can be considered as a determinant of death within the confirmed cases of COVID-19. The implementation of a general mandatory quarantine did not show a curve-flattening effect in Ecuador and Peru but did so in Colombia. The implementation of Mask obligation in public spaced showed positive impact on the distribution of confirmed case in both countries tested.

Conclusion: The implementation of a general mandatory quarantine does not guarantee the curve-flattening effect. Various macro indicators should therefore always be considered while analyzing the effect of policies.

Keywords: COVID-19, Latin America, coping strategies, macro indicators, ITSA = interrupted time-series analysis, country comparison, mandatory quarantine, mask obligation

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INTRODUCTION

A new coronavirus (SARS-COV-2/COVID-19) emerged on December 12, 2019 in Wuhan, China (1). In the following months, the disease spread around the world. The World Health Organization (WHO) declared the coronavirus outbreak a Global Public Health Emergency on January 20, 2020. On March 11, the WHO determined that COVID-19 can be characterized as a pandemic (2). Due to the high number of cases and the rapid spread, healthcare systems are facing the most serious global pandemic crisis in a century [(3), p. 1].

The lack of knowledge about remedies and vaccinations are a problem straining the stability of healthcare systems (4, 5). The need to implement policies to reduce the incidence of infection is in danger of overloading hospital capacities and healthcare systems. The healthcare systems in Latin American Countries (LAC) have been shaped by the history of the worst income inequalities worldwide [(6), p. 1230]. Universal access to healthcare is included as a basic right in the constitution of each country (7, 8). However, the availability and the access to healthcare, even in countries with universal coverage, are unequal [(3), p. 3]. Accordingly, nearly 30% of the people in the lowest income quintile forgo care because affordability in OECD countries (3). With the increasing spread of SARS-COV-2 viruses, the demands on these unevenly distributed healthcare systems are growing. The critical task of healthcare systems is to protect the health of all citizen, especially in times of pandemics such as COVID-19 [(8), p. 9].

Many healthcare systems in LAC are characterized by fragmentation because providing a clear typology for health coverage is a difficult endeavor [(9), p. 15]. In some countries, such as Mexico, coexisting models and overlapping coverage makes it difficult to define the percentage of population with healthcare coverage (7, 10, 11). In this mode, being affiliated or contributing to a health system does not necessarily guarantee effective access or the quality of services received [(10), p. 38]. The generally weak and fragmented health systems are even more strained by the COVID-19 pandemic, as they have already been hit by Zika and Chikungunya outbreaks [(10, 12), p. 38]. A syndemic[1] of measles, dengue, and COVID-19, among others, makes it all the more important for countries in the region to keep COVID-19 cases low (12). For example, in Ecuador, 82.57% of the confirmed COVID-19 cases and 84% of dengue cases are present in the coast and the city of Guayaquil (13). Efforts to stop the spread of the virus could be undermined by gaps in access to health services and the quality received [(10), p. 38]. The lack in the availability of intensive care units and specific diagnostic tests has been a concern regarding the upcoming health crisis (12). A baseline scenario during the outbreak of an healthcare crisis is imbalance between supply and demand for medical resources, which may grow rapidly in many countries [(14), p. 1]. To face the demand surge from COVID-19, health workforces, such as doctors and nurses, are key indicators of a timely and effective response [(8), p. 10]. The number of beds to cope with the increasing demand for hospital service due to the spread of the virus is indicative of how prepared the healthcare systems are (8).

TABLE 1 | Indicator of the Healthcare Systems (latest year available).

	Hospital beds × 1,000 inhabitants	Doctors × 1,000 inhabitants	Nurses × 1,000 inhabitants	Out-of-pocket (OOP) share of health spending (%)
Chile	2.1	2.5	2.7	34
Colombia	1.7	2.2	1.3	16
Costa Rica	1.1	3.1	3.4	22
Ecuador	1.5	2.0	2.5	39
Mexico	1.4	2.4	3.9	41
Peru	1.6	1.3	2.4	28

OECD (8).

With the aim to measure the general access to healthcare, Out-of-Pocket (OOP)[2] may be considered, as it highlights barriers to access. On average, 34% of the total health spending in LAC are OOP [(8), p. 9]. On the OECD average, the OOP expenditures are above 21% (8). It can be said that a higher level of OOP spending indicates weaker healthcare Systems in the LAC with lower levels of health service coverage and an overall worse baseline scenario to confront health crisis (8). The basic characteristics of the healthcare systems are displayed in **Table 1**.

The spread of the virus, and with this, the likelihood of the healthcare system to collapse, is influenced by various macro indicators. Firstly, higher population density may increase the chances of human interaction [(15), p. 117]. Due to higher population density, the human interactions may increase, which favors the spread of viruses (15). In the past, it has been shown that densely populated urban areas have been more likely to be affected by epidemics of respiratory diseases, such as in the influenza pandemic of 1918–1919 (16). Secondly, age and underlying health conditions have been shown to be indicators determining the likelihood of infection, critical conditions, and consequently passing away due to the infection (17). Dowd et al. (18) showed a higher fatality among countries with a higher share of older citizen compared to younger societies. The likelihood of entering a critical condition thus increases with age, which leads to a higher demand for hospital care units within the healthcare system. It can thus by hypothesized that the hospitals are facing a higher demand with an increase in the share of older populations, which can increase the likelihood for a collapse of the healthcare system.

In LAC, a high degree of informality and inequality make the situation potentially more catastrophic compared to other parts in the world [(8), p. 11]. A lack of social protection likely results in the need to continue to work to make a living, which limits the capability to follow social distancing measures (8). Moreover, the possibility of working from home, overcrowded conditions, and lack of access to water and sanitation restricts the capability

[1] Interlinked health problems.

[2] Direct payments made by individuals.

TABLE 2 | Marco indicator (latest date available).

	GDP per capita in $ (2018)[a]	Population density (2018)[b]	Poverty headcount ration at national poverty lines (%)[c]	Population aged 65+ (%)[d]	Urban population (%)[e]	Sanitation (%)[d]	Access to drinking water (%)[d]
Chile	14,670	25.189	8.6 (2017)	11.530	84.8%	100	100
Colombia	6,180	44.749	27.0 (2018)	8.478	80.4%	90	97
Costa Rica	11,520	97.913	21.0 (2019)	9.550	80%	98	100
Ecuador	6,110	68.789	25.0 (2019)	7.157	63%	88	94
Mexico	9,180	64.915	41.9 (2018)	7.224	83.9%	91	99
Peru	6,470	24.992	20.5 (2018)	8.088	79.1%	74	91

[a] *Worldbank (21).*
[b] *Worldbank (22).*
[c] *Worldbank (23).*
[d] *OECD (8).*
[e] *Worldometer.info (24).*

of individuals to cope with health emergencies such as COVID-19 [(4, 19, 20), p. 5]. Supporting the inequalities based on the access to clean water, Brojas (20) found a higher probability of having a positive COVID-19 test result for people living in poor neighborhoods, in neighborhoods where large numbers of people reside together within the same household, and in neighborhoods with a large black or immigrant population, like in New York [The United States (U.S.)]. Based on this, the macro indicators of the countries under study are displayed in **Table 2**.

In order to narrow the gap between medical need and available supply of treatments, public health measures known to reduce viral spread, such as social distancing and hand hygiene, may be implemented [(14, 25), p. 3]. During the implementation of measures against the spread of the virus, policy makers must draw on knowledge from previous pandemics and epidemics. A useful reference in the evaluation of possible policies aiming to flatter the curve of SARS-COV-2 is SARS-COV (SARS) (25). To control person-to-person transmission, measures such as isolation, quarantine, social distancing, and community containment were implemented in the main affected countries of China, Taiwan, Hong Kong, Singapore, and Canada in order to lower the transmission of the virus (25). Patients suspected of having SARS were isolated in either their homes, a hospital, or in government-designated places (e.g., hotels) until SARS could be ruled out (25). Individual interactions were reduced, responsibility to self-identify the disease and social distance were encouraged, and cancellation of public gatherings and implementation of community quarantine were introduced (25).

Researchers have already conducted studies testing the efficiency of various measures against the spread of COVID-19. Figueiredo et al. (26) have shown that the social distancing measures in two Chines provinces were effective in reducing incidences and mortality rates of COVID-19 (26). It has been shown that the effectiveness of lockdown policies declines with GDP per capita, population density and surface area and it increases with health expenditure and proportion of physicians in population (15).

Most of the Latin American Countries (LAC) remembered the lessons learned during SARS-COV and the influenza pandemic of 2009 (12). However, the strategies aiming to lower the infected and death by COVID-19 vary. A range of non-pharmaceutical Interventions (NPI) have been implemented, including closure of schools, mandatory healthcare coverage, mandatory quarantine, and aiming to increasingly reduce the population contact rates and slow the transmission of the virus. The present study focuses on six Latin American countries, Chile, Colombia, Costa Rica, Ecuador, Peru, and Mexico. The selection of the countries was made based on the availability of data on health systems in the case of Colombia, Chile, and Mexico as OECD countries. In addition, COVID-19 infection and death rates have been considered to allow the formation of synthetic cohorts. Furthermore, the countries were selected according to the implemented policies, so that countries with different coping strategies are included. **Table 3** shows the main policies aiming to reduce the spread of the virus implemented the countries under study. All countries included in the study had implemented at least six policies by May 17 (27).

The aim of this study is to analyze whether and to what extent the implementation of a general mandatory quarantine and mask obligation in public spaces affect the distribution of COVID-19 cases. In addition, the impact of resources in the healthcare systems and several macro indicators of the death due to COVID-19 will be described. For this purpose, a data set was assembled from various data sources. The individual sources are Our World in Data based on the European Center for Disease Prevention and Control, the websites of the governments of the countries included, the World Bank, WorldOMeter, and OECD. By now, various studies have been conducted to test the effect of implemented policies on the curve of cases and death due to COVID-19. However, most are conducted for industrial countries such as U.S.A., China or Spain (20, 26, 28). This study therefore aims to close the research gap by conducting a country comparison of the influence of macro indicators in six different LAC in order to provide deeper knowledge about the spread of COVID-19.

TABLE 3 | Number of actions (regarding health) implemented by the countries (state of May 17th).

	Chile	Colombia	Costa Rica	Ecuador	Mexico	Peru
Health emergency	1	3	2	1	1	1
Mandatory coverage	0	1	1	1	0	0
Mandatory quarantine for foreign travelers, confirmed or suspected cases	1	1	1	1	0	1
Mandatory general quarantine	0	5	0	3	1[a]	1
Type of policy on testing (universal, reduced to certain groups, etc.)	2	1	3	1	1	3
Free test coverage expansions	1	2	2	1	1	0
Hospitals	3	2	6	0	1	0
Face masks in public transport/closed public spaces	1	1	0	0	0	0
Other	0	1	3	2	1	0
Total	9	17	18	10	6	6

CEPAL and United Nations (27).
[a]*Not mandatory yet.*

DATA AND METHODS

Data and Variables

The data for the analyses were obtained from various sources. For this reason, the data origin is described together with the description of the variables so that it is possible to determine which data source is relevant for each variable.

Data of confirmed COVID-19 case per million inhabitants and the fatality per million inhabitants were obtained by Our World in Data (29). The platform collects data published by the European Center for Disease Prevention and Control (ECDC) and makes it available for free (29).

For the purpose of measuring the effect of the implemented policies, the last date of observation is set on May 24, as this was the beginning of the relaxing of the restrictions. Data starting February 29 until May 24 are included in the dataset. However, the starting point for each country is set to the first confirmed case and until 77 days after for each country. Since SARS-CoV-2 has an average incubation period of 5.1 days, with 97.5% of cases progressing to COVID-19 at around 11.5 days, it is assumed that the cases diagnosed in the first days after the implemented policies were infected before the implementation (26, 30). For this reason, a delayed effect of the implemented policies must be assumed.

Missing values in the data of confirmed cases and death of COVID-19 were found in the following cases and dates: Costa Rica on March 8 and Ecuador on March 7 and March 8. In the case of both cases, the missing values were found in the first week after the confirmation of the first COVID-19 value in the country. Since the number of reported new cases has been below 5 in both cases before and directly after the event, it has been assumed that no new cases were reported on the missing dates. The missing dates were therefore imported with the value 0 for new cases and death.

Data of the implemented policies are taken from the websites of the governments of the countries studied (31–35). With the aim to prevent errors in the data collection process, the collected data is double checked with OECDs report "COVID-19 in Latin America and the Caribbean: An overview of government responses to the crisis" (2020). The implemented policies are coded according to the date of implementation after the first confirmed case as dummy variables (0/1).

The macro indicators in the study are collected from the "World Bank World Development Indicators," "WorldOMeter," and "OECD" (see **Table 1**) (23, 24). All platforms make macro indicators from different countries available for use free of charge.

Methods

Interrupted Time Series Analysis

All analyses will be done using STATA 15.1 and Microsoft Excel 365. The analyses are organized as follows. First, descriptive analysis of the impact of macro indicator on the distribution of cases and death is provided. Second, an Interrupted Time Series Analysis (ITSA) is conducted to examine whether the implementation of a certain policy has taken a decreasing effect on the distribution of the cases per million inhabitants.

ITSA is a quasi-experimental design with which longitudinal effect of interventions can be modeled though regressions. It is run by the STATA command *itsa* (36). Due to the data structure, statistical analysis used for ITSA must account for auto correlated data [(36) f]. In order to do so, an Ordinary Least Squares (OLS) regression model designed for autocorrelation using Newey-West estimators is employed, which controls for autocorrelation and heteroscedasticity in the error terms [(37), p. 639].

In order to specify the lags of the serial correlation in the data, the STATA command *actest* is used (38). It performs a Cumby-Huizinga general test for autocorrelation in time series data with the null hypothesis that serial correlation exists in the time series, but it dies out at a known finite lag ($q > 0$) (38). The lag in which the series correlation dies out will be included into the ITSA model in order to control for it.

In this study, the outcome variable in both cases are the confirmed cases per million inhabitants. The time elapsed since the start of the study is measured in days. The ITSA assumes the following form (36, 39):

$$Y_t = \beta_0 + \beta_1 T_t + \beta_2 X_t + \beta_3 X_t T_t + \epsilon_t$$

Y_t indicates the outcome variable measured at each time point t. β_0 represents the starting level (intercept) of the outcome

TABLE 4 | Percentage of death within the confirmed cases and macro indicators.

	Chile	Colombia	Costa Rica	Ecuador	Mexico	Peru
% of death within the confirmed cases	1.00	3.60	1.10	14.50	10.50	2.90
Poverty headcount ration at national poverty lines (%)	8.6	27.0	21.0	25.0	41.9	20.5
Urban Population (%)	84.8	80.4	80	63	83.9	79.1

TABLE 5 | Percentage of death within the confirmed cases and healthcare systems.

	Chile	Colombia	Costa Rica	Ecuador	Mexico	Peru
% of death within the confirmed cases	1.00	3.60	1.10	14.50	10.50	2.90
Resources (per 1,000 inhabitants)	2	2	3	2	3	2
Hospital beds (per 1,000 inhabitants)	2.1	1.7	1.1	1.5	1.4	1.6
Doctors (per 1,000 inhabitants)	2.5	2.2	3.1	2	2.4	1.3
Nurses (per 1,000 inhabitants)	2.7	1.3	3.4	1.5	3.9	2.4
Out-of-pocket (OOP) share of health spending (%)	34	16	22	39	41	28

TABLE 6 | Results single ITSA–General Mandatory Quarantine.

	Colombia				Ecuador				Peru			
	Implementation of the Intervention (Model 1a)		+ 14 days delay (Model 1b)		Implementation of) the Intervention (Model 2a)		+ 14 days delay (Model 2b)		Implementation of the Intervention (Model 3a)		+ 14 days delay (Model 3b)	
	β-Coefficient	Std. error	β-Coefficient	Std. error	β-Coefficient	Std. error	β-Coefficient	Std. error	β-Coefficient	Std. error	β-Coefficient	Std. error
Pre-intervention intercept	−0.942**	0.345	−0.942**	0.350	0.201***	0.022	0.201***	0.022	−0.139**	0.045	−0.139**	0.046
Pre-intervention slope	0.271***	0.042	0.271***	0.042	0.096***	0.004	0.096***	0.004	0.160***	0.011	0.160***	0.011
Immediately post (day of implementation)	−48.488*	22.63	0.763	0.677	−374.069**	149.866	−13.942***	3.556	−681.412*	307.459	−0.432	0.236
Difference between pre- and post-Intervention slopes (day of implementation)	5.244***	0.754	1.548***	0.096	34.131***	3.578	7.245***	0.485	45.727***	8.231	1.323***	0.034
Immediately post (14 days delay)			−36.925	18.838		−233.389**	3.062			−588.751*	225.507	
Difference between pre- and post-Intervention slopes (14 days delay)			5.106**	0.796		34.720***	3.062			59.412***	7.368	

*Significance levels: *p < 0.05, **p < 0.01, ***p < 0.001.*

variable. β_1 is the prior intervention trend, β_2 represents the immediately occurring change in the level of the outcome variable after the introduction of the intervention, β_3 is the treatment effect over time, which is the difference between pre-intervention and post-intervention slops of the outcome, and ϵ_t represents the random error term. Due to the incubation time of COVID-19, the analysis will focus on β_3 rather than β_2. A single-group ITSA is designed without a comparable control group; it rather projects the pre-intervention trend into the treatment period, which serves as the counterfactual [(36), p. 482].

Considering the multiple-group ITSA, the main assumption tested is that the exogenous policy shift affects all the groups [(36), p. 484]. The change in the outcome variable is therefore presumed to be the same for both the control and the treatment group (36). The regression equation is expanded by four additional terms (β_4 to β_7) [(36), p. 483]. A dummy variable to denote the cohort assignment (treatment or control) Z is introduced.

$$Y_t = \beta_0 + \beta_1 T_t + \beta_2 X_t + \beta_3 X_t T_t + \beta_4 Z + \beta_5 Z T_t + \beta_6 Z X_t + \beta_7 Z X_t T_t + \epsilon_t$$

In the case of the multiple-group ITSA β_0 to β_3 represent the values of the control group and β_4 to β_7 represent the values of the treatment group. Going into detail, β_4 represents the differences between treatments and controls prior to the intervention in the intercept of the outcome variable. β_5 represents the prior intervention difference in the slope of the outcome variable. β_6 represents the difference between treatment and control immediately following the introduction of the

TABLE 7 | Results multiple ITSA–General Mandatory Quarantine.

	Colombia				Ecuador				Peru			
	Implementation of the Intervention (Model 4a)		+ 14 days delay (Mode 4b)		Implementation of the Intervention (Model 5a)		+ 14 days delay (Model 5b)		Implementation of the Intervention (Model 6A)		+ 14 days delay (Model 6b)	
	β-Coefficient	Std. error	β-Coefficient	Std. error	β-Coefficient	Std. error	β-Coefficient	Std. error	β-Coefficient	Std. error	β-Coefficient	Std. error
Pre-intervention intercept	−0.797	0.420	−0.797	0.426	−0.034**	0.012	−0.034**	0.112	−0.099	0.053	−0.099	0.054
Pre-intervention slope	0.257***	0.052	0.258***	0.052	0.128***	0.002	0.128***	0.002	0.146***	0.129	0.146***	0.013
Intercept differences between treatment and control pre-Intervention	−0.145	0.596	−0.145	0.604	0.236***	0.027	0.236***	0.027	−0.040	0.077	−0.040	0.078
Slope differences between treatment and control pre-Intervention	0.014	0.073	0.014	0.074	−0.032***	0.005	−0.032***	0.005	0.015	0.019	0.015	0.019
Immediately post (day of implementation)	−92.218	0.073	−0.278	0.836	−51.409*	24.367	−0.523	0.294	−314.366*	139.847	−6.348*	2.524
Difference between pre- and post-Intervention slopes (day of implementation)—control group	8.698***	1.516	2.152***	0.152	3.995***	0.730	0.732***	0.043	24.640***	4.453	3.614***	2.524
Difference between pre- and post-Intervention intercept (day of implementation)—treatment group	43.729	49.160	1.041	1.100	−322.660*	151.718	−13.419**	4.010	−367.046	332.908	5.916*	2.540*
Difference between pre- and post-Intervention Slope (day of implementation)—treatment group	−3.454*	1.705	−0.604**	0.199	30.136***	3.686	6.513***	0.547	21.087*	9.375	−2.292***	0.381
Immediately post (day of implementation) 14 days			−77.039*	38.157			−44.668*	20.798			−232.530	125.683
Difference between pre- and post-Intervention slopes (day of implementation)—control group 14 days			9.288***	1.652			4.497	0.767			27.608***	5.066
Difference between pre- and post-Intervention intercept (day of implementation)—treatment group 14 days			40.114	42.843			−188.721	100.574			−326.221	263.356
Difference between pre- and post-Intervention Slope (day of implementation)—treatment group 14 days			−4.181*	1.856			30.223***	3.296			31.804**	9.145

*Significance levels: *p < 0.05, **p < 0.01, ***p < 0.001.*

intervention and β_7 represents the difference between treatment and control in the slope after initiation of the intervention comparing with pre-intervention.

Synthetic Control Unit

A synthetic control unit is a comparison unit as a linear combination of the untreated units with coefficients that sum to one [(40), p. 7] in order to test against the counterfactual. It is estimated by a weighted average of the untreated units that closely match the treated unit over the pre-treatment period [(41), p. 843]. The estimation is done using the STATA package synth (40–42). In order to test whether the synthetic cohort serves as a valid counterfactual, some outcomes in the pre-treatment period are excluded from the list of predictors to check whether the synthetic control matches well with the treated unit in these periods [(41, 43), p. 838].

RESULTS

The dataset includes the confirmed cases and deaths in Chile from March 4 to May 22, in Colombia from March 7 to May 22, Costa Rica from March 7 to May 22, in Ecuador from March 1 to May 19, Mexico from February 29 to May 15, and Peru from March 7 to May 22.

TABLE 8 | Results single ITSA–Mask Obligation.

	Chile				Colombia			
	Implementation of the Intervention (Model 7a)		+ 14 days delay (Model 7b)		Implementation of the Intervention (Model 8a)		+ 14 days delay (Model 8b)	
	β-Coefficient	Std. error	β-Coefficient	Std. error	β-Coefficient	Std. error	β-Coefficient	Std. error
Pre-intervention intercept	−90.088*	37.745	−90.088*	38.272	−4.024*	1.706	−4.024*	1.730
Pre-intervention slope	10.113***	1.619	10.113***	1.641	0.720***	0.125	0.720***	0.127
Immediately post (day of implementation)	−186.244**	111.460	97.284*	39.287	−35.116	18.991	5.702**	1.952
Difference between pre- and post-Intervention slopes (day of implementation)	48.785***	7.837	13.840***	1.770	5.758***	0.804	2.479***	0.137
Immediately post (14 days delay)			−114.530*	52.841			−36.609*	13.975
Difference between pre- and post-Intervention slopes (14 days delay)			63.210***	5.239			5.228***	0.727

*Significance levels: *p < 0.05, **p < 0.01, ***p < 0.001.*

TABLE 9 | Results multiple ITSA–Mask Obligation.

	Chile				Colombia			
	Implementation of the Intervention (Model 9a)		+ 14 days delay (Model 9b)		Implementation of the Intervention the Intervention (Model 10a)		+ 14 days delay (Model 10b)	
	β-Coefficient	Std. error	β-Coefficient	Std. error	β-Coefficient	Std. error	β-Coefficient	Std. error
Pre-intervention intercept	−69.970	37.753	−69.970	38.280	−3.716*	1.603	−3.716*	1.626
Pre-intervention slope	6.703**	1.909	6.703**	1.936	0.705***	0.115	0.705***	0.115
Intercept differences between treatment and control pre-Intervention	−20.118	55.024	−20.118	55.794	−0.309	2.367	−0.309	2.401
Slope differences between treatment and control pre-Intervention	3.410	2.538	3.410	2.574	0.015	0.168	0.015	0.171
Immediately post (day of implementation)	−93.226	74.074	135.830**	47.152	−263.564*	109.830	−11.163*	5.613
Difference between pre- and post-Intervention slopes (day of implementation)—control group	79.538***	5.948	47.556***	4.592	34.784***	3.936	11.342***	0.927
Difference between pre- and post-Intervention intercept (day of implementation)—treatment group	−93.018	136.201	−38.546	62.604	228.449*	111.521	16.864**	5.980
Difference between pre- and post-Intervention Slope (day of implementation)—treatment group	−30.753**	9.876	−33.717***	4.965	−29.026***	4.022	−8.863***	0.937
Immediately post (day of implementation) 14 days			42.725	28.994			−144.841*	55.686
Difference between pre- and post-Intervention slopes (day of implementation)—control group 14 days			48.168***	5.057			33.826***	3.295
Difference between pre- and post-Intervention intercept (day of implementation)—treatment group 14 days			−157.254*	66.735			108.233	57.528
Difference between pre- and post-Intervention Slope (day of implementation)—treatment group 14 days			15.045	7.829			−28.598***	3.374

*Significance levels: *p < 0.05, **p < 0.01, ***p < 0.001.*

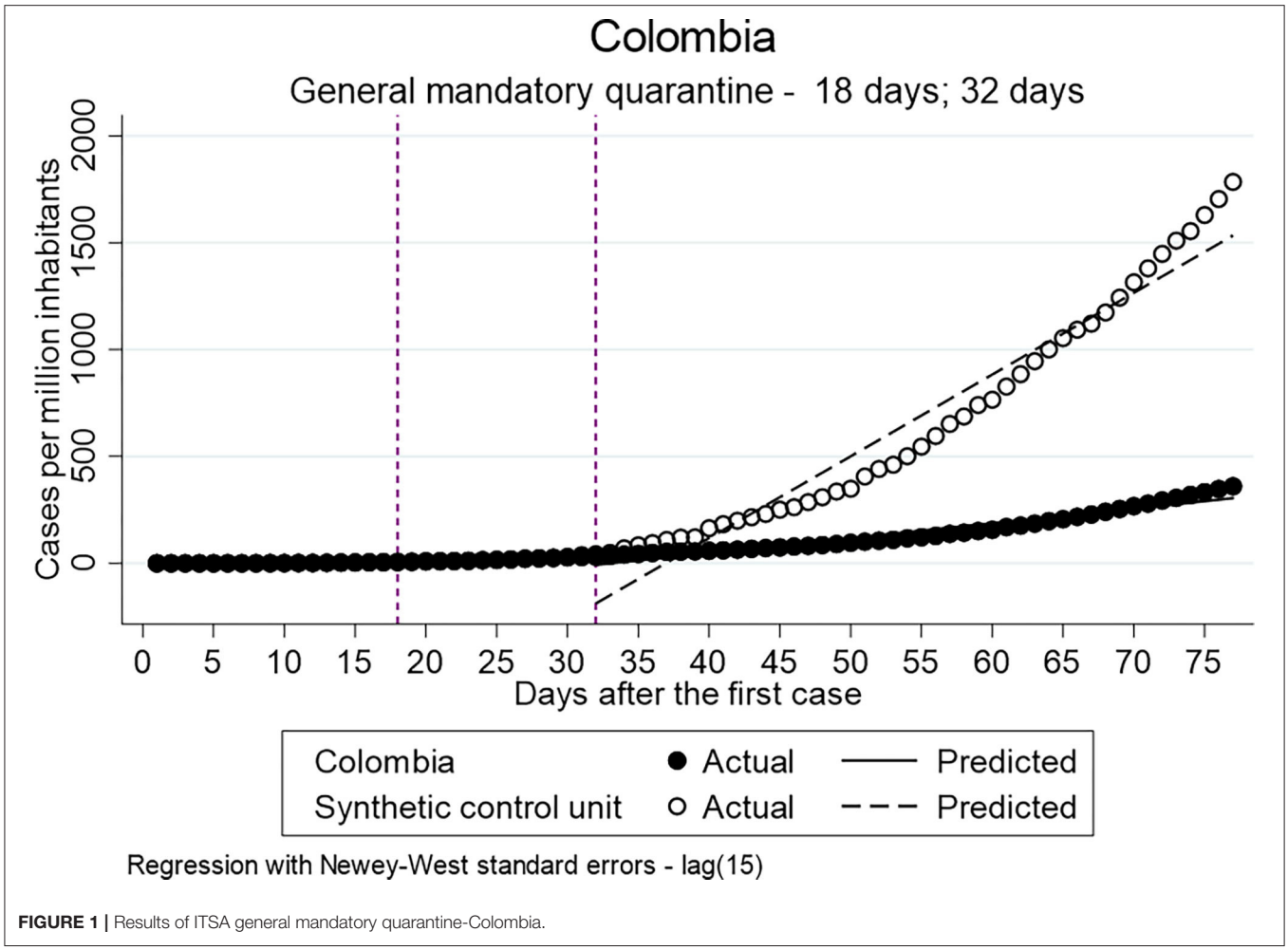

FIGURE 1 | Results of ITSA general mandatory quarantine-Colombia.

Macro Indicator and Healthcare System

The analyses of the impact of the healthcare systems and macro indicator on the distribution of death and cases is based on the descriptive statistics. The dependent variable is the provenance of deaths as a proportion of the number of confirmed cases per million inhabitants per day. The values show that in Ecuador 14.50% of the confirmed cases died on day 77. In Mexico 10.50% died, in Colombia 3.60%, in Peru 2.90%, in Costa Rica 1.10%, and in Chile 1%.

Firstly, it is assumed that a higher poverty headcount ratio at national poverty lines and a lower percentage of the population living in urban areas leads to an increase in the percentage of death within the confirmed COVID-19 cases.

Table 4 indicates that Mexico has the highest poverty headcount ratio at the national level (41.9%) and the second highest percentage of death within the confirmed cases (10.5%). Chile shows the lowest poverty headcount ratio in terms of the national poverty lines (8.6%) and the lowest percentage of death within the confirmed cases (1%). These findings are in line with the assumption that a higher poverty headcount ratio at national level leads to a higher percentage of death within the confirmed cases. However, Ecuador displays a lower poverty ratio (25%) compared to Colombia (27%) but a higher percentage of death within the confirmed cases (14.5% Ecuador; 3.5% Colombia).

Regarding the influence of the percentage of the population living in urban areas, the lowest amount is shown by Ecuador (63%) and the highest amount is shown by Chile (84.8%). In addition, Ecuador shows the highest percentage of death within the confirmed cases (14.5%), and Chile shows the lowest percentage of death within the confirmed cases (1%). The findings reveal no clear trend for the poverty headcount ratio at the national poverty lines nor for the percentage of the observable urban population.

Now we turn to the assumption that higher resources in the healthcare system of a country lead to a lower percentage of death within the closed cases. The reported resources in the following are always to be interpreted as resources per 1,000 inhabitants. The results in **Table 5** indicate no visible direction of the influence of the resources in the healthcare systems on the percentage of death within the confirmed cases regarding the resources in total (summed up). However, no trend within the distribution of the resources is visible in the sense that none of the countries have reported a low/high number of beds, doctors, and nurses. Chile, as the country with the lowest percentage of death

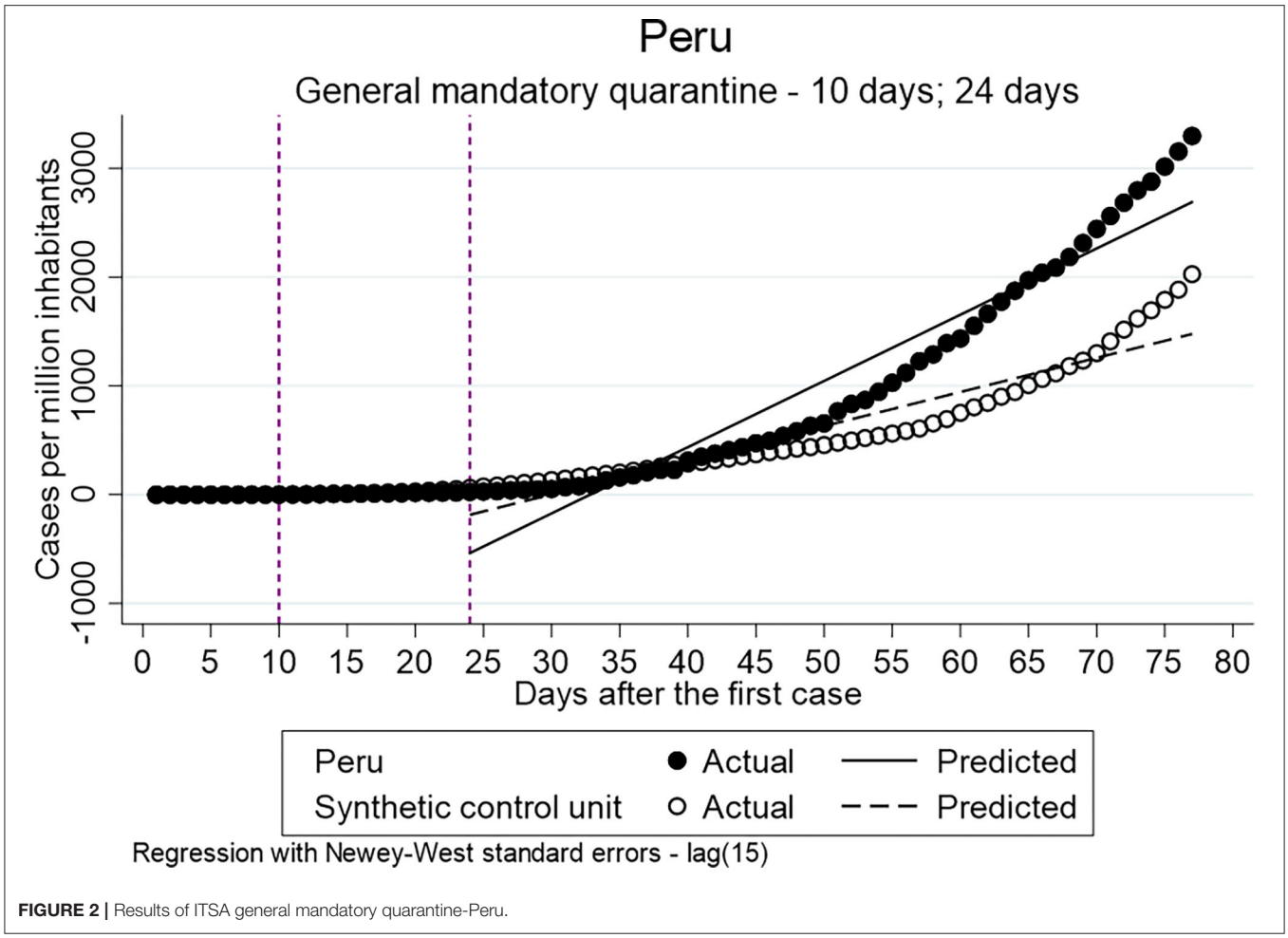

FIGURE 2 | Results of ITSA general mandatory quarantine-Peru.

within the confirmed cases, has the highest amount of hospital beds (2.1) and a high number of doctors (2.5). However, Costa Rica, as the country with the second lowest percentage of death, has the lowest number of hospital beds (1.1) and the highest number of doctors (3.1). The number of doctors in Mexico (2.4) is nearly as high as in Chile (2.5), but the percentage of death within the confirmed cases is the second highest (10.5%). A possible explanation could be an uneven distribution of hospital beds within countries. It is conceivable that the cases clustered occur in certain regions that may not have enough beds available. It is therefore not the total number of beds in the country that is relevant but the number of beds in the regions concerned.

The results in **Table 5** indicate that the countries with the highest share of OOP spending in the health spending show the highest percentage of death within the confirmed cases (Ecuador 14.5%; Mexico 10.5%). However, the share of OOP spending is higher in Mexico compared to Ecuador, and the percentage of death is lower. The share of OOP spending of Peru and Chile are higher compared to Colombia even though they report a lower percentage of death. The same is true for Costa Rica. The country with the lowest share of OOP spending does not report the lowest percentage of death among the cases.

Implemented Policies

To investigate whether the implemented policies have an influence on the distribution of the confirmed cases and death due to COVID-19, ITSA was employed. The first model includes the implementation of the policy at the time of entry into force. In the second model, a delay of 14 days is included as second interruption time point in order to control for the expected time lack due to the incubation time. Due to the expected time delay between implementation and change in confirmed cases, the intercept will not be discussed in the analysis. Finally, multiple ITSA under the use of the synthetic control unit, following the same method as the single ITSA, are conducted.

To estimate the effect of the implementation of the general mandatory quarantine in Colombia, Peru and Ecuador directly after the implementation and 14 days later various ITSA models have been estimated. **Table 6** presents the parameter estimates. This analysis examines the hypothesis that the implementation of a general mandatory quarantine has a decreasing effect on the distribution of confirmed cases.

Focusing on the slope, ITSA identified significant interruptions in both time points for Colombia (Model 1B). The starting level of cases per million inhabitants is -0.942 ($p \leq 0.00$)

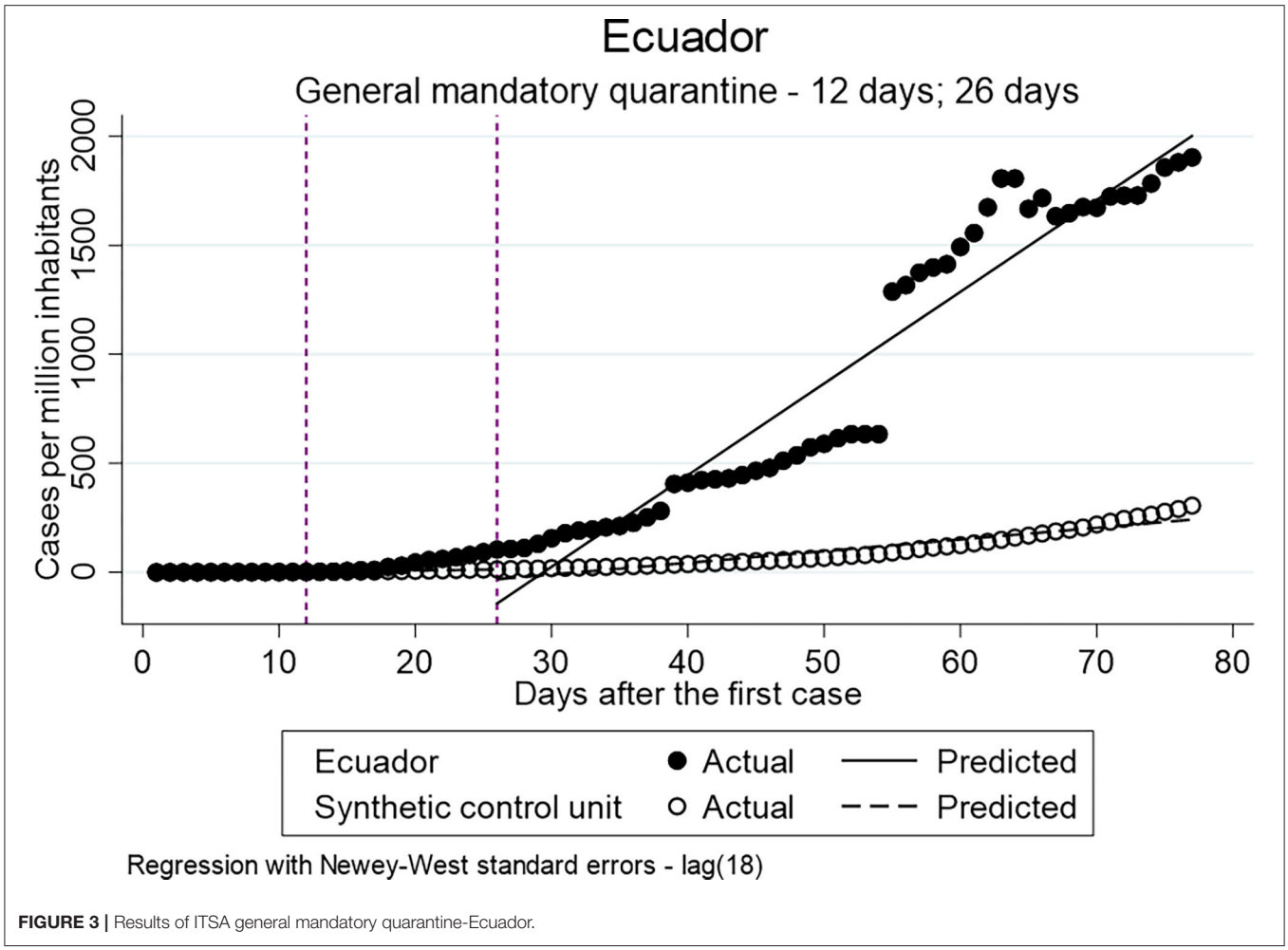

FIGURE 3 | Results of ITSA general mandatory quarantine-Ecuador.

with an increasing slope in comparison with the pre-intervention period of 1.548 ($p \leq 0.00$) at the first interruption point. The second interruption point has shown in comparison with the pre-intervention period an increasing slope of 5.106 ($p \leq 0.01$). In other words, the distribution increased after both interruption time points in comparison with the pre-intervention period.

The estimates of the difference between pre-intervention and post-intervention at both time points (the actual implementation day and 14 days later) show that the difference of the slope is statistically significant for all three countries. However, the estimated coefficients of Colombia 14 days after the implementation (ß = 5.106) are smaller compared to Ecuador (ß = 34.720) and Peru (ß = 59.412), which indicates a lower increase in the distribution.

Figure 1 shows the distribution of the confirmed cases per million inhabitants vs. the counterfactual in Colombia. It indicates that the implementation of the general mandatory quarantine decreased the number of cases. **Figures 2**, **3** show a higher distribution of confirmed cases in Peru and Ecuador compared with the counterfactual. The multiple group ITSA in **Table 7**, Model 4B identifies a significant positive coefficient of the slope difference between pre-and post-Intervention periods for the treatment group at the first interruption time point (ß = 1.548) and 14 days after the implementation of the policy for Colombia (ß = 5.106). In other words, the analysis identifies a significant effect of the mandatory general quarantine in Colombia against the counterfactual.

For both, Ecuador (Model 5a/b) and Peru (Model 6a/b), the estimates indicate higher values of confirmed cases per million inhabitants for the treatment group compared to the control group. The implementation of the mandatory general quarantine is hypothesized to have a reducing effect on the number of infected and death, therefore, the results of the multiple ITSA for Ecuador and Peru will not be discussed further. The hypothesis cannot be accepted.

To investigate whether the obligation to wear face masks in public transport and/or closed public spaces has a decreasing effect on the distribution of the confirmed cases per million inhabitants when single and multiple ITSA for Colombia and Chile were employed. The policy was implemented by Chile and Colombia 43 and 28 days after the first confirmed case, respectively.

Table 8 shows the results of the single ITSA. Statistically significant differences between the pre- and post-intervention periods can be identified by the analysis for both countries. However, similar to the previous models in **Table 7**, the

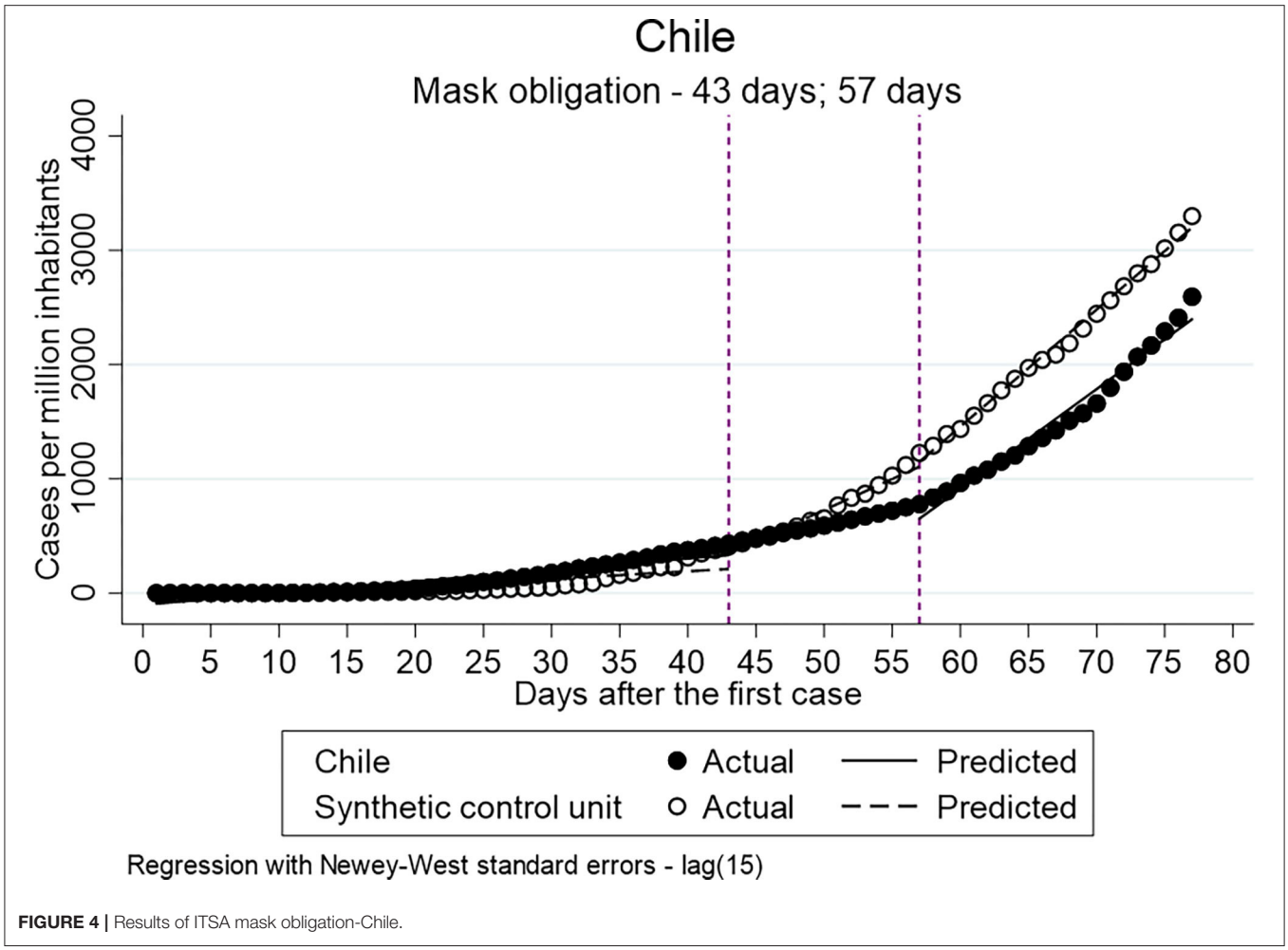

FIGURE 4 | Results of ITSA mask obligation-Chile.

coefficients indicate an increase in the confirmed cases per million inhabitants in the post-intervention period, and, therefore, it is indicated that the implementation did not have a decreasing effect on the distribution.

The multiple ITSA using synthetic control units are displayed in **Table 9**. In **Figures 4**, **5** the results are visualized. The results of the model, including the delay of 14 days after the implementation, identify for both countries a significant decreasing effect of the policy on the distribution of confirmed cases per million inhabitants. The Intercept of the treatment group in Colombia indicates higher values for Colombia in comparison to the synthetic control units at both time points (ß = 16.854; ß = 108.233) even though the only the coefficient of the immediately post-intervention is statistically significant. The slopes between the pre- and post-Intervention period of the treatment group indicate significantly less confirmed cases compared to the control unit (ß = −8.863; ß = −28.598). In the case of Chile, only the coefficient of the difference between the pre- and post-Intervention period in the period immediately after the implementation is statistically significant and negative (ß = −33.717). The coefficient of the 14-day delay indicates a higher number of confirmed cases in the slope between pre-and post-intervention period for the treatment group compared to the control group, which is, however, not statistically significant (ß = 15.045). In summary, the results of the multiple ITSA for Chile and Colombia generally indicate that the introduction of compulsory masks has reduced the spread of the virus.

DISCUSSION

The objective of the study was to show whether the proportion of deaths among COVID-19 cases and the efficiency of NPIs are influenced by macro indicators of the countries under study. Firstly, this study shows no clear influence of the macro indicator poverty headcount ratio at national poverty lines and urban population on the percentage of death within the confirmed cases. The same is true for the resources of the healthcare system and the access to those measured by OOP spending. However, Ecuador and Mexico report the highest percentage of death among the confirmed cases, and they report the highest share of OOP spending. The data indicates that higher OOP spending takes an impact on the percentage of death among the confirmed cases. Among the countries with a lower share of OOP spending, no trend is visible. Further research should therefore address the question whether OOP spending has an impact on the percentage of death among.

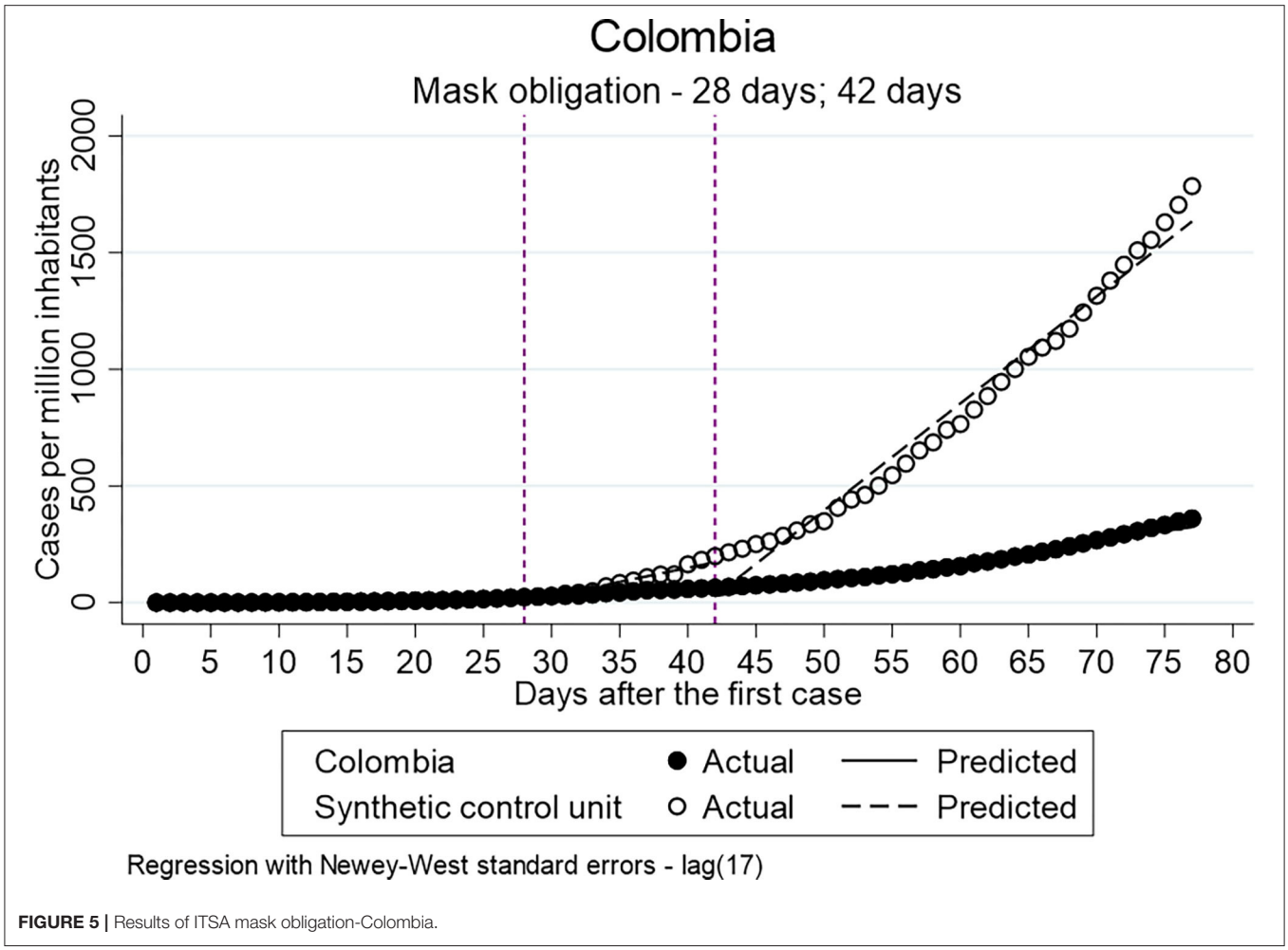

FIGURE 5 | Results of ITSA mask obligation-Colombia.

Secondly, the most important finding of this study concerns the effect of the implemented policies on the distribution of the confirmed cases. The first analysis showed a positive impact of the implementation of a mandatory general quarantine on the distribution of confirmed cases for Colombia but not for Ecuador and Peru. Peru and Ecuador share similar patterns in the OOP share of health spending, which is higher compared to Colombia. The percentage of poverty headcount ratio and national poverty lines is higher in Colombia compared to Ecuador and Peru. Health system resources are similar in all three countries. Even though the poverty in Colombia is higher, the access to drinking water and sanitation in Colombia is better compared to Peru and Ecuador (8). The need for access to sanitation and drinking water as basic human needs determine the possibility of keeping the quarantine, and, for this reason, it is conclusive that the inhabitants of Peru and Ecuador had less opportunity to carry out the quarantine compared to Colombia. In addition, factors such as informal employment increasing the need to leave to house in order to provide for living could play a role, which cannot be sufficiently verified due to lack of data [cf. (44)]. It must be considered that only countries that have implemented the policy during the time of observation can be considered in the discussion.

Finally, the analyses have shown that the introduction of mask obligation in Colombia and Chile has had a positive effect on the reduction of COVID-19 cases. In this sense, the analyses show that the effect of obligation to wear a mask is less influenced by external factors such as poverty compared to general quarantine. However, the mask obligation was only implemented by two out of six countries under observation. The result therefore only accounts for Chile and Colombia but not for the other countries.

The results indicate that the effect of the implemented policies depends on various factors and the implementation of a policy is not a guarantee of a flattened curve. These results go in line with those of previous studies, which showed that the efficiency of lockdown measures is influenced by various macro indicators such as population density (26).

Several limitations must be borne in mind when interpreting the findings of this study. Firstly, it must be considered that only reported and confirmed cases can be included in the analysis. This paper only refers to reported cases of COVID-19 diseases published by the respective countries. In this sense, the number of unreported cases, which is estimated differently depending on

the reproductive value, cannot be included (45). The possibility of a bias due to a high number of unreported cases exists, depending on the testing frequency of the countries. As data on testing performed are not sufficiently available for the countries treated, it was not be possible to control for it [cf. (29)]. In addition, only policies from the country level were treated. Countries that have mainly implemented policies at the state level, as it is the case in Mexico, were treated as countries with no/fewer implemented policies. This approach was chosen to manage complexity, which also leads to a possible bias. Furthermore, not all countries publish data on health insurance coverage, which is why the share of OOP was chosen to include the health system [cf. (8)]. Moreover, additional resources of the healthcare system could not be included because in this case, too, there was no consistent transparent reporting by the countries at the time of the research. Future studies should therefore include (as much as possible) the additional resources and tests done by the states in order to control for those biases.

Healthcare system resources and OOP spending could only be included in the analysis to a certain extent. Since the focus was on the impact of the introduction of quarantine and the introduction of the obligation to wear a mask, only those countries that have introduced it could be compared. Countries that did not introduce the mask obligation were generally neglected in the analyses and played an important role in the formation of the synthetic control unit. In future studies, however, all countries should be analyzed, possibly including more measurement dates. The Model Fit must also be considered. The analyses show high standard errors for some coefficients, which indicate a bad model fit. Nevertheless, the standard errors of the coefficients relevant for the analysis are not too high.

The work provides above all an explorative overview in a field that is new and largely untreated. Previous analyses have mainly referred to industrialized countries but not to developing countries. Future research must therefore further address whether and how policies that have been effective in industrialized countries can make an impact in developing countries with different demographic characteristics and challenges.

DATA AVAILABILITY STATEMENT

The original contributions presented in the study are included in the article, further inquiries can be directed to the corresponding author.

AUTHOR CONTRIBUTIONS

AP contributed to the design and implementation of the research, to the analysis of the results and to the writing of the manuscript.

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Conflict of Interest: The author declares that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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frontiers in Public Health

OPINION
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Return-to-School Evaluation Criteria for Children With Suspected Coronavirus Disease 2019

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During the coming winter, the spread of Coronavirus disease 2019 (COVID-19) will co-exist with other common viral infections. Even if most of the children with COVID-19 are asymptomatic or have minimal symptoms, they can still spread the virus to vulnerable adults. The correct clinical diagnosis of mild cases of COVID-19 becomes often extremely difficult since the presenting symptoms could be similar with other common viral illnesses. Furthermore, each child may have several viral infections during the winter and in conjunction with insufficient supplies and the high cost of SARS-CoV-2 PCR-RT test in several countries makes the diagnosis of COVID-19 a very complicated one. We should also consider the whole cascade of consequence from children's lack of school attendance ranging from family's financial security to support the children's educational needs and the emotional well-being. The school absence could compromise the ability of parents to go to work due to possible lack of child care with major economic effects since in 73% of the families with school age children in the United States, both parents are employed (1). Similarly, the parental employment status in Australia has been reported to be about 69% (2), while in Europe the percentage of both parents having full time employment reaches 41% (3). Regarding alterations in education, COVID-19 pandemic has a catalytic impact on the educational system that had to adopt new learning modalities and move to distant learning. However, 31% of school age children around the globe do not have access to remote schooling (4). American Academy of Pediatrics strongly advocates the in person education for the present school year stressing the facts that staying away from school for a long time can result in social isolation and complicates the recognition and management of learning deficits (5). Even if blended educational curriculums have been implemented by several institutes (6), it seems that in person schooling has major advantages especially for young children. The goal is the children to attend school regularly and to minimize as much as possible the disruptive quarantine period with the major concern of the students' protection from COVID-19.

As the flu season is approaching in Northern hemisphere and the schools are reopened, the government officials are taking actions for managing the childhood minor respiratory infections in COVID-19 era. Several policies have been established in different countries with the goal to minimize the risk of transmission of SARS-CoV-2 (7–9). In addition, clinical algorithms treated children suspected with COVID-19 have been designed (10). However, the question remains as to when a child with symptoms of a viral illness can safely return to school reducing the unnecessary home stay. Trying to answer that question, we develop a return-to-school criteria for children with fever and/or cough combining several clinical and epidemiological parameters and taking into consideration the limited supply and the expense of SARS-CoV-2 PCR-RT test (**Figure 1**).

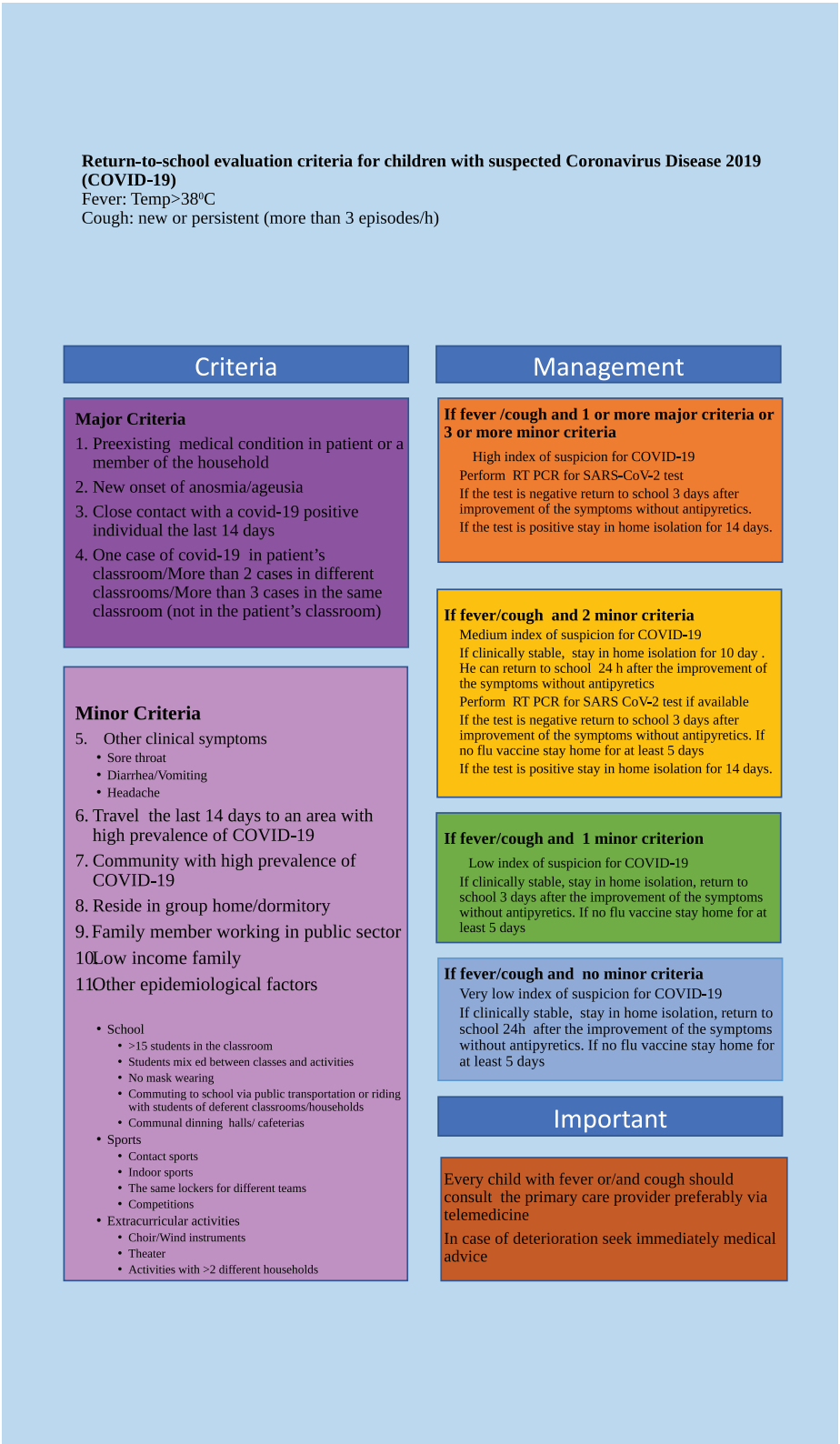

FIGURE 1 | Return-to-school evaluation criteria for non-hospitalized children with suspected Coronavirus Disease 2019.

The goal of this algorithm is not only to make a safe decision to return-to-school but also to reduce the school absence as much as possible. Among the major criteria are the close, recent contact with a person with COVID-19, a vulnerable child or a family member and a new onset of anosmia and/or ageusia, characteristic symptoms for COVID-19 (11). One major criterion is enough to place the child in high risk and to require a SARS-CoV-2 RT-PCR test. The children can return to school if the test is negative, they are afebrile without antipyretics, and the other symptoms are improved for at least 3 days. Considering the possibility of a SARS-CoV-2 RT-PCR false negative test result, a 3-day interval with significant improvement of the symptoms without antipyretics was advised prior to return to school. The minor criteria consist of a combination of clinical and epidemiological factors. We select the most common epidemiological circumstances that place the child in very close proximity with other classmates during different activities at school, extra curriculum, sports, school dinning, and school transit. The community spread of the disease and living in close community have also been considered. A limit of 15 students in the classroom was selected based on the experience at Denmark and Norway. They have shown no increase in the rate of COVID-19 by decreasing the class size to <15 students (12). Another study contacting in Tokyo metropolitan area revealed that the class reduction and the social distancing of at least 1.5 m reduces the school closure due to flu pandemic by 90% (13). Centers of Disease Control and Prevention (CDC) and World Health Organization have published recommendations for schools, school dinning, school transit, and sports (7, 8). Those are based on maintaining physical distance among students during their activities. Several of those guidelines have been incorporated into our proposed stratification criteria. One of the minor criteria is the use of public transportation for school transit. A study in the Zhejiang province, China has been shown that riding a bus makes 42.2 (95% CI, 2.6–679.3) times more likely to develop COVID-19 if a fellow passenger is positive to SARS-CoV-2 (14). An additional criterion we include in the present algorithm is the use of face masks in the classroom. Many health authorities recommend the proper use of face masks by students and teachers (5, 8). Eikenberry et al. have evaluated the effectiveness of mask wearing in the community by developing model simulations. Those results indicate that the use of even moderately (50%) effective masks could prevent, on the range of 17–45%, the projected deaths over a 3 month period in New York City (15). In addition, an epidemiologic analysis have shown that the viral transmission from pre-symptomatic patients was significantly lower in mask-wearing persons compare to unmasked ones (19.0% vs. 8.1%, $p < 0.001$) (16). A family member working in the public sector has been also added as a minor criterion due to facilitation of community transmission of SARS-CoV-2 in that case. We have also included the family with low income status as it has been shown that the people living in poorer and more diverse areas have a high incidence of COVID-19 (17). The children with three or more minor criteria are considering as high risk and SARS-CoV-2 PCR-RT test is required. The cases with two minor criteria are assigned to medium risk and we propose to stay in home isolation for 10 days. SARS-CoV-2 PCR-RT test is advised if available. The children with none or one minor criterion are appointed to very low and low risk and they return to school when they are afebrile without antipyretics and the symptoms are improved for 24 h and 3 days, respectively. In the setting of no flu vaccine, the child should stay home for at least 5 days to minimize the risk of flu transmission and to avoid the co-infection between flu and COVID-19 (18, 19). Influenza immunization is strongly recommended during the present winter by the CDC (20). We would like to emphasize that the caregivers should consult their primary care physician regularly, during the home isolation period preferably via telemedicine and if the patient deteriorates they should ask immediately medical advice (10).

These stratification criteria, combining clinical and epidemiological factors, could be a useful tool for the primary care physicians to evaluate a child with fever and/or cough and make a safe return-to-school decision minimizing the unnecessary home stay. It is important, this proposed algorithm, to be revised as new data becomes available.

AUTHOR CONTRIBUTIONS

VV and GF contributed equally to the design, analysis, and writing of the manuscript.

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Conflict of Interest: The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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Spatial Autocorrelation and the Dynamics of the Mean Center of COVID-19 Infections in Lebanon

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In this paper we study the spatial spread of the COVID-19 infection in Lebanon. We inspect the spreading of the daily new infections across the 26 administrative districts of the country, and implement the univariate Moran's *I* statistics in order to analyze the tempo-spatial clustering of the infection in relation to various variables parameterized by adjacency, proximity, population, population density, poverty rate and poverty density. We find out that except for the poverty rate, the spread of the infection is clustered and associated to those parameters with varying magnitude for the time span between July (geographic adjacency and proximity) or August (population, population density and poverty density) through October. We also determine the temporal dynamics of geographic location of the mean center of new and cumulative infections since late March. The understanding of the spatial, demographic and geographic aspects of the disease spread over time allows for regionally and locally adjusted health policies and measures that would provide higher levels of social and health safety in the fight against the pandemic in Lebanon.

Keywords: COVID-19, spatial autocorrelation, mean center of infection, Lebanon, mathematical modelling

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1 INTRODUCTION

The spread of COVID-19 pandemic has practically affected the entire planet, and created enormous challenges on every aspect of human life and organization, starting with the health sector and with far reaching consequences on the economy, education, sports, transportation and politics. Since the first cases were registered in Wuhan, China in December 2019 [1], the global spatial dynamics of the infection have been changing as the disease swiftly moved toward the West [2] into Europe then into the United States, South America, and eventually to the whole world, with nearly 38.1 million cases and 1.1 million deaths registered until October 12, 2020 [3].

Given the global geographic spread of the virus and the local wide spread in many countries, and the nature of the transmission of the virus, it is important to understand the spatial mechanisms of this spread and its dependence on proximity, demographics and social characteristics of infected areas. Spatial analysis provides a better understanding of the routes of transmission of infections [4], consequently, it allows the decision-makers to draft and implement effective health and mitigation measures to reduce risks associated with the pandemic.

In Lebanon, the first case was registered on February 21, 2020 [5] and by October 12, 54,624 cases and 466 deaths were registered [6]. The first few weeks witnessed a relatively rapid increase but it sharply declined as a result of the strong mitigation measures enforced by the beginning of March. The lift of the international travel ban and the partial easing of measures led to the revival of higher

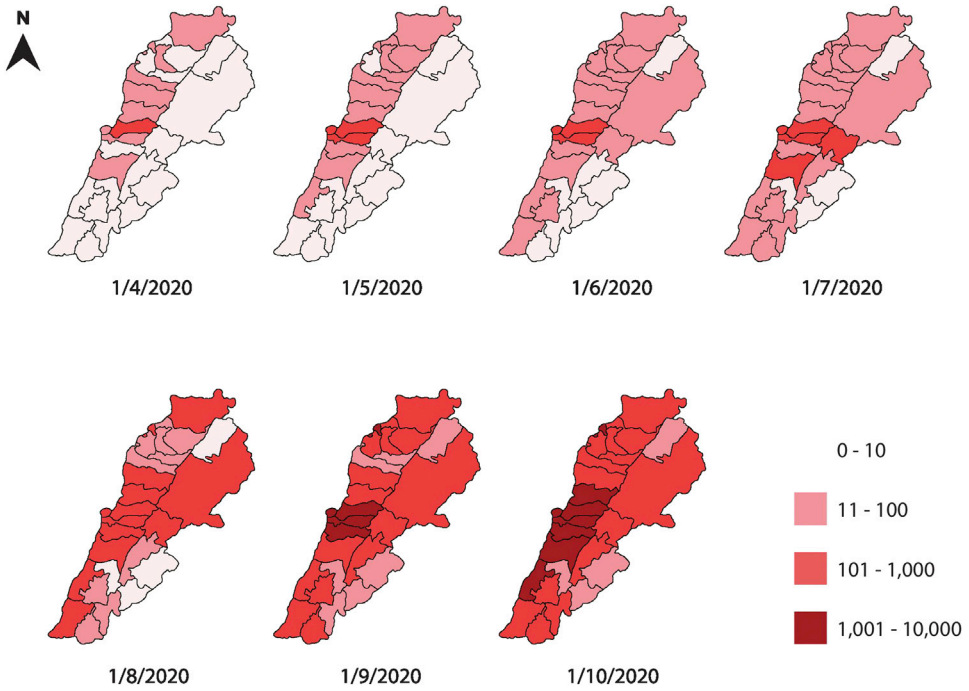

FIGURE 1 | A monthly map of the regional cumulative number of infections in Lebanese districts between April and October 2020. The figure shows a time series of the infection spread, using a logarithmic scale to account for the rapid increase in the number of infections. The central neighboring districts of Beirut and Mount Lebanon are the most infected throughout the time span studied.

spread rates since July. Only 1,788 cases were registered by July 1, 2020 before a sharp rise from July through October. The cases were mainly concentrated in Beirut, its suburbs and its neighboring areas in Mount Lebanon. On August 4, a huge explosion rattled the port of Beirut and destroyed thousands of houses and buildings in the surrounding areas. People were rushed into hospitals, with thousands of injuries recorded on that day [7]. On such a horrible incident, hundreds of volunteers and civil defense teams were involved in rescue work for several days. The social distancing measures were largely neglected in such an emergency situation. The spread accelerated in the upcoming weeks, with sharp rise in Beirut and its surroundings and with a national widespread reaching all regions and major towns and cities [8].

Related Literature: Spatial autocorrelation is the statistical analysis of data studied in space or in space-time aiming for the identification and estimation of spatial processes [9, 10]. It has been implemented to study and analyze the spread of various diseases and infections including cancer, diabetes, SARS, influenza virus, COVID-19, etc. [11–14]. The concept of geographical spatial autocorrelation has been expanded into the study of clustering of infections, including that of the Coronavirus, among regions sharing similar (neighboring) demographic or social features [4, 15, 16]. Recent studies also inspected the effect of city size, population, transportation systems and demographics on the disease spread and its mortality rate [17–21]. The understanding of spatial spread dynamics is essential for drafting and implementing preventive measures in the fight against infectious diseases including the most recent spread of COVID-19 [22, 23].The determination of the mean center of a population (centroid) was discussed in Refs. [24–26] and extending the concept to the determination of the mean center of wealth and infections allowed for a spatial analysis of the temporal dynamics of wealth distribution, economic growth and infectious diseases [27]. The dynamics of the outbreak of COVID-19 in Lebanon and its reproduction number dynamics were studied in Refs. [28–31]. Recent publications explored other aspects of the spread in Lebanon on the preventive level [32] as well as on the level of psychological, pharmaceutical and mental needs and responses to face the consequences of the infection [33–35].

Despite the accelerating spread in Lebanon (see **Figure 1**), there are no relevant studies analyzing the spatial dynamics of the Coronavirus infections in the country. In this paper, we study the clustering and spatial progression of new infections in Lebanon by applying the methods of spatial autocorrelation with different model parameterizations of geographic, demographic and social variables including adjacency, proximity, population, population density, poverty rate and poverty density. Locating the mean center of the epidemic spread as a function of time is used to analyze the temporal geographic development of the spread. The methods used are general, but our current work is focused on spatial dynamics only in Lebanon. The paper has many novel aspects as it addresses and studies the spatial spread of COVID-19 in

TABLE 1 | The table shows the distribution of the cumulative number of cases among the 26 Lebanese districts on October 12, 2020, with their respective populations, population densities, poverty rates and poverty densities.

Region name	Number of cases (Cumulative)	Population × 100	Population denisty (Resident/km^2)	Poverty Rate (%)	Poverty density (Resident/km^2)
Akkar	1,171	3,204	418	38.4	38
Minieh-Denniyeh	723	1,408	389	48.6	189
Tripoli	4,198	2,438	9,030	31.7	2,862
Zgharta	854	877	399	25	100
Koura	556	846	489	14.3	70
Bcharre	115	221	140	13.4	19
Batroun	341	589	212	5.5	12
Jbeil	954	1,295	301	12.7	38
Kesrwan	1978	2,605	762	18.5	141
Meten	6,139	5,110	1928	20.4	393
Beirut	6,443	3,417	17,258	25.5	4,401
Baabda	7,277	5,538	2,855	26.8	765
Aley	3,047	3,008	1,144	29.4	336
Chouf	1965	2,770	560	24.2	135
Jezzine	125	321	133	21.9	29
Saida	2,472	2,966	1,079	19.1	206
Nabatieh	683	1802	593	28.2	167
Sour	1,023	2,557	933	30.3	283
Bent Jbeil	331	962	364	22.9	83
Marjeyoun	214	740	279	24.2	68
Hasbaya	76	287	108	23.9	26
Rachaya	79	338	62	16	10
West Beqaa	474	864	184	25.5	47
Zahleh	2,367	1774	424	37.3	158
Baalback	877	2,146	94	40.6	38
Hermel	86	305	42	47.1	20

Lebanon covering the existing gap in current literature. It also introduces the analysis of spread in relation to social characteristics of infected regions by analyzing the effects of poverty rate and poverty density, and applies the concept of the mean center of infection on the spread of the Coronavirus. The obtained results provide a solid basis for the concerned policy makers to draw well-grounded and scientifically based local and regional measures that would contribute to controlling the infection spread in the country.

The paper is organized as follows: in **section 2** we introduce the implemented analytic mathematical and statistical methods and tools. Results are presented and discussed in **section 3**, and **section 4** concludes the paper.

2 ANALYTIC METHODS AND TOOLS

2.1 Moran's I Index

Moran's I index is a univariate inferential statistic used to measure the spatial autocorrelation based both on locations and feature values simultaneously. It is defined as Ref. [9]:

$$I = \frac{N\Sigma_{ij} W_{ij}\left(X_i - \overline{X}\right)\left(X_j - \overline{X}\right)}{\Sigma_{ij} W_{ij}\Sigma_i \left(X_i - \overline{X}\right)^2} \tag{1}$$

where W_{ij} represents different types of adjacency between region i and region j, corresponding to different models of infectious spread. N is the number of regions under consideration and Xi represents the number of new daily infections in district i. $\overline{X}$ is the average number of new daily infections per region, and it is given by $\overline{X} = \frac{\Sigma_i X_i}{N}$. The numerical outcome of I falls between −1 and 1 and it indicates whether a distribution is dispersed, random or clustered. A value of I close to 0 indicates a random distribution, while positive values indicate clustered spatial distribution and negative values indicate dispersion. Larger values of $|I|$ nearer to 1 mean stronger clustering (positive I) or stronger dispersion (negative I).

The z_I-score associated to this statistic is defined by:

$$z_I = \frac{I - E[I]}{\sqrt{V[I]}} \tag{2}$$

where the expected value $E[I]$ and the variance $V[I]$ are defined in the Appendix. The z-score or the corresponding p-value of the statistic are used to reject the null hypothesis, eliminate the possibility of a random pattern leading to the obtained value of the Moran I statistic and ensuring the normality of the distribution under consideration.

2.1.1 Methodology

In this paper, we take a confidence level corresponding to $|z_I| > 1.96$ or equivalently to $p < 0.05$ in order to confirm the outcome of clustering or dispersion of our spatial data indicated by I. In this case we say that the p-value is statistically significant and the distribution is normal, and based on the value of I we can determine the pattern of the distribution.

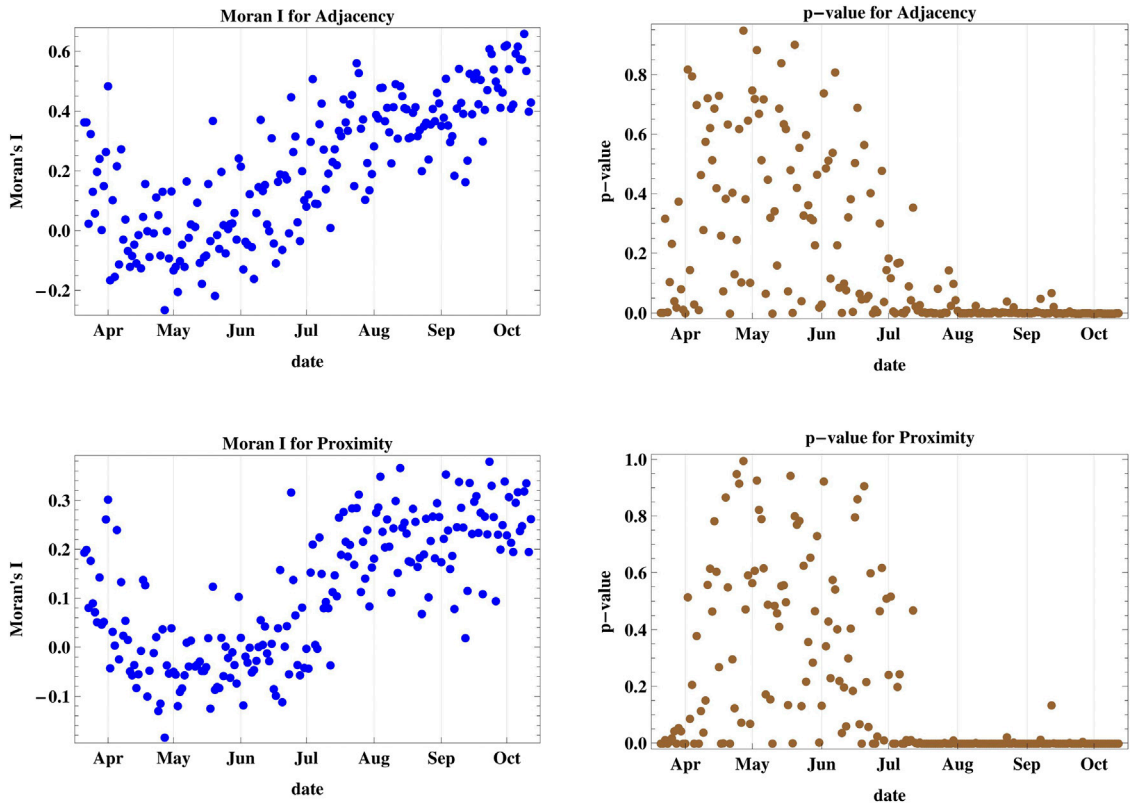

FIGURE 2 | The figure shows Moran's *I* index and its corresponding *p*-value for cases I and II accounting for adjacency and proximity of new infections registered in Lebanese districts. Since July, there is a strong clustering of daily infections in regions sharing common borders and among nearer regions.

We consider a model with six different cases of parameterization of the adjacency matrix W_{ij} corresponding to geographic adjacency (case I), proximity (case II), population (case III), population density (case IV), poverty rate (case V) and poverty density (case VI). The first four cases follow analogous parameterizations to those implemented in Refs. [4, 16], while cases V and VI introduce a new parameterization in order to inspect possible effects of poverty rate and poverty density on the viral spread. **Table 1** summarizes relevant data from the Lebanese districts.

In case I, we take $W_{ij} = 1$ for districts sharing common borders, and contributing to spatial spread, and $W_{ij} = 0$ otherwise assuming that the spread does not occur directly between non-neighboring districts. In case II we determine $W_{ij} = \frac{1}{d_{ij}}$ where d_{ij} is the driving distance between the administrative centers of regions i and j, thus assumes that the geographic spatial spread is inversely proportional to distance between districts. Those two cases study the effect of administrative adjacency and the distance proximity of different districts on the geographic clustering of new infections in Lebanon.

In case III and case IV, we analyze the effects of population and population density on the spread of the disease since the virus is carried by people and its spread is supposed to be related to their interaction. We sort the districts by the number of their residents (obtained from Ref. [36]) and then by the density of their residents relative to their areas, inspecting spread between districts according to similarities in their inhabitants' number and density respectively. Using the sorted order of residents and densities, districts of consecutive number of residents and population densities are assigned a factor of $W_{ij} = 1$, and $W_{ij} = 0$ otherwise. This provides a statistic about the clustering of infections according to population and population density respectively.

Lastly, in cases V and VI, we introduce new parameters, namely the poverty rate and the poverty density in different districts and we analyze their effect on infection clustering. We sort the districts by their poverty rates and poverty density [36] and assign $W_{ij} = 1$ for regions of consecutive order of poverty rate or poverty density, and $W_{ij} = 0$ otherwise, in a similar methodology to cases III and IV in order to infer the effect of similarities in poverty rate and density on patterns of infection spread.

2.2 Mean Center of Infection

The mean center of infection (henceforth MCI) is a geographic location that represents the weighted mean of the positions of infected individuals on the surface of Earth, assumed to be spherical. Assigning the value of Earth's radius to unity, the two spherical coordinates that determine the unique

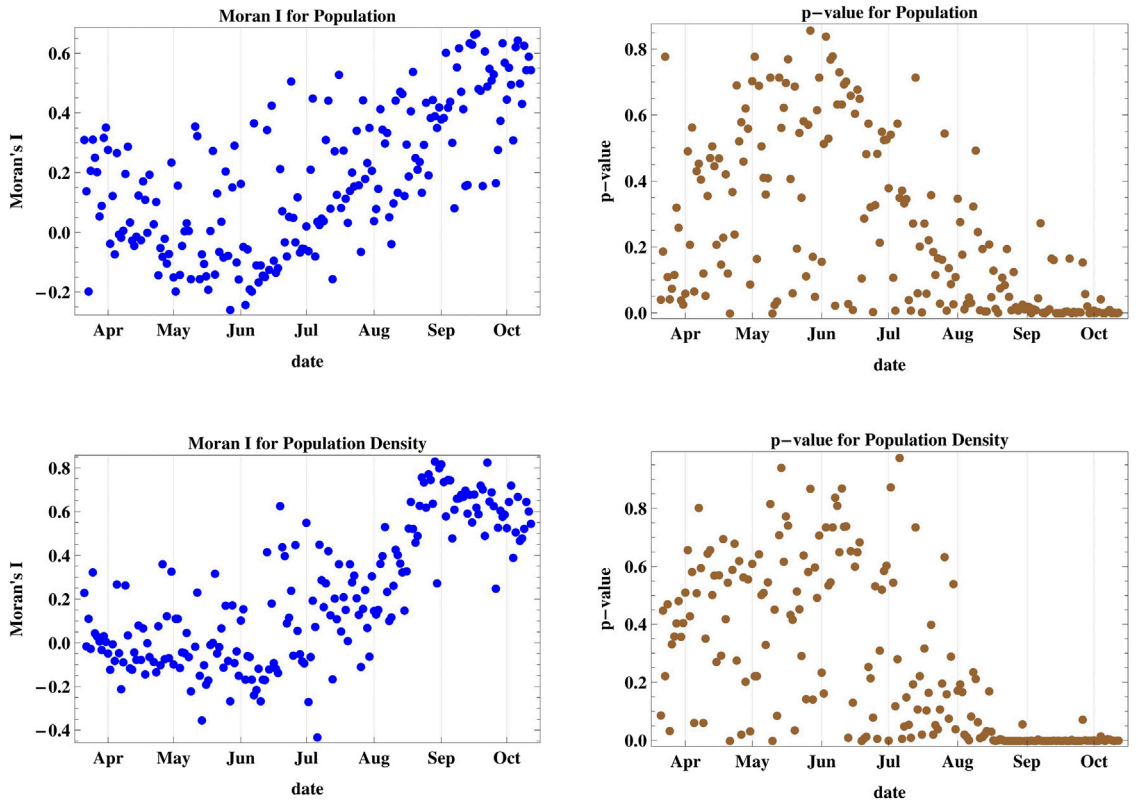

FIGURE 3 | Moran's I index and its corresponding *p*-value for cases III and IV accounting for population and population density of different districts. The daily spread was not clustered with respect to district population and density until late August 2020, where it started achieving strong spatial clustering between districts of adjacent population ranks.

position of a point are its latitude λ_i and longitude ϕ_i. The latitude is a measurement of location north or south of the equator while the longitude is a measurement of location east or west of the prime meridian at Greenwich, United Kingdom.

The Cartesian position vector $\overrightarrow{r_i} = (x_i, y_i, z_i)$ is related to spherical coordinates with unit radius by the relations Ref. [37]:

$$\begin{cases} x_i = \cos\lambda_i \cos\phi_i \\ y_i = \sin\lambda_i \cos\phi_i \\ z_i = \sin\phi_i \end{cases} \tag{3}$$

We denote the district number of infections (new or cumulative) by X_i as defined above, and the Cartesian positions of the administrative centers by (x_i,y_i,z_i). Then, the Cartesian position of the weighted mean of infections $\overrightarrow{\hat{r}_i}$ is given by:

$$\begin{cases} \hat{x} = \dfrac{\Sigma_i X_i x_i}{\Sigma_i X_i} \\ \hat{y} = \dfrac{\Sigma_i X_i y_i}{\Sigma_i X_i} \\ \hat{z} = \dfrac{\Sigma_i X_i z_i}{\Sigma_i X_i} \end{cases} \tag{4}$$

As suggested by Ref. [24], the precise position on the surface of a sphere can be determined from the normalized position vector defined by $\overrightarrow{\overline{r}_i} = (\overline{x}, \overline{y}, \overline{z}) = \dfrac{\overrightarrow{\hat{r}_i}}{\left|\overrightarrow{\hat{r}_i}\right|}$,leading to

$$\begin{cases} \overline{x} = \dfrac{\hat{x}}{\sqrt{\hat{x}^2 + \hat{y}^2 + \hat{z}^2}} \overline{y} = \dfrac{\hat{y}}{\sqrt{\hat{x}^2 + \hat{y}^2 + \hat{z}^2}} \overline{z} = \dfrac{\hat{z}}{\sqrt{\hat{x}^2 + \hat{y}^2 + \hat{z}^2}} \end{cases} \tag{5}$$

Consequently, we can recover the spherical position of the mean center of infections by calculating the mean latitude and longitude as:

$$\begin{cases} \overline{\phi} = \sin^{-1}\overline{z} \\ \overline{\lambda} = \tan^{-1}\dfrac{\overline{y}}{\overline{x}} \end{cases} \tag{6}$$

The latitude and the longitude can be located and plotted on maps and geographic information systems. We employ the spherical coordinates of geographic locations of the capitals of the 26 administrative districts in Lebanon and the number of daily and cumulative infections in each region in order to determine the daily MCI accordingly. This provides a tool to analyze the temporal dynamics of the mean geographic spread of the disease.

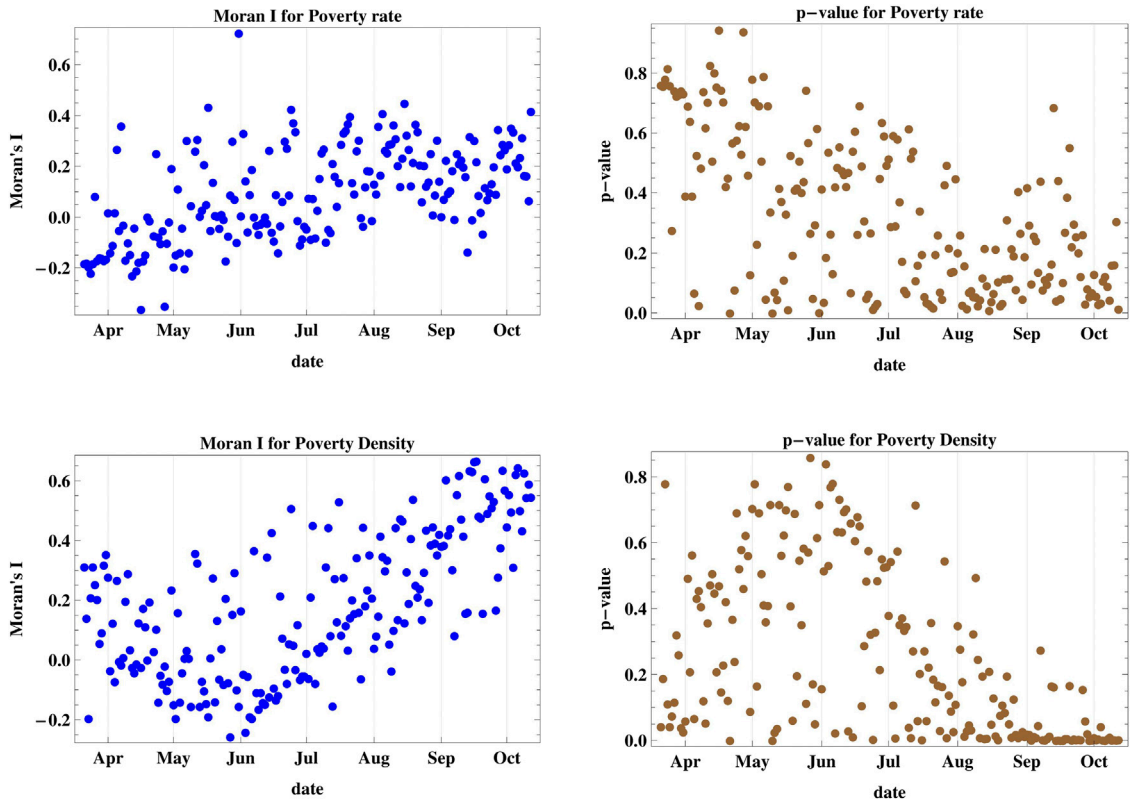

FIGURE 4 | Moran's I index and its corresponding *p*-value for cases V and VI accounting for regional poverty rate and poverty density. The poverty rate is not a decisive factor for spatial spread but when we consider the poverty density, we obtain spatial clustering starting on the end of August.

3 RESULTS AND DISCUSSIONS

The determination of the Moran's *I* index and its corresponding *p*-value for the effect of adjacency and proximity of cases I and II on the clustering of daily new infections of COVID-19 in Lebanon shown in **Figure 2**, leads to the conclusion that since July 2020, there is strong clustering of infections in regions sharing common borders and among nearer regions. There were only few days when new infections were not clustered in adjacent regions, and only one day where distance was not shown to be a detrimental effect in the spatial spread of new cases. The maximum value of Moran's *I* reached 0.660 for case I and 0.380 for case II indicating a high level of geographic clustering of the disease spread since July. The infections before July had a high *p*-value, indicating a high probability for random geographic spread.

The results of the spatial spread dynamics in relation to population and population density adjacency as shown in Moran's *I* and *p*-value of cases III and IV depicted in **Figure 3** reveal that the spread was not clustered with respect to the regional population until late August 2020, where it started achieving a positive value of *I* with $p < 0.05$ indicating spatial clustering between regions of adjacent population rank, with several days showing a probability of random spread. The maximum attained *I* was 0.666. However, the statistics for districts with adjacent rank of population density show very strong spatial clustering since the middle of August with *I* attaining a maximum value of 0.832, which is the highest among all six studied cases.

The results of case V (**Figure 4**) show that the spatial spread cannot be attributed to adjacent ranking of poverty rates among the districts since the *p*-values remain above the 5% level of confidence up until October 2020, hence no spatial clustering occurs. But when we consider the poverty density in case VI, we obtain positive values for Moran's *I* since the end of August, with $p < 0.05$ except for five days. Hence, spatial clustering among regions with adjacent ranking of poverty density occurs. The maximum attained *I* in this case is 0.666.

In comparison, we find out that clustering of new infections occurs starting on different dates between July and August for all considered cases except for case V corresponding to district populations. The strongest level of spatial clustering (highest *I*) occurs for model IV of population density after mid-August, while clustering associated to geographic adjacency and proximity (cases I and II) has the longest time span (since early July) and the highest levels of confidence.

By construction, spatial autocorrelation and its corresponding Moran's *I* index are defined in terms of univariate data observations [10, 38, 39]. Multivariate spatial analysis implies a compromise between multivariate analysis (relations among

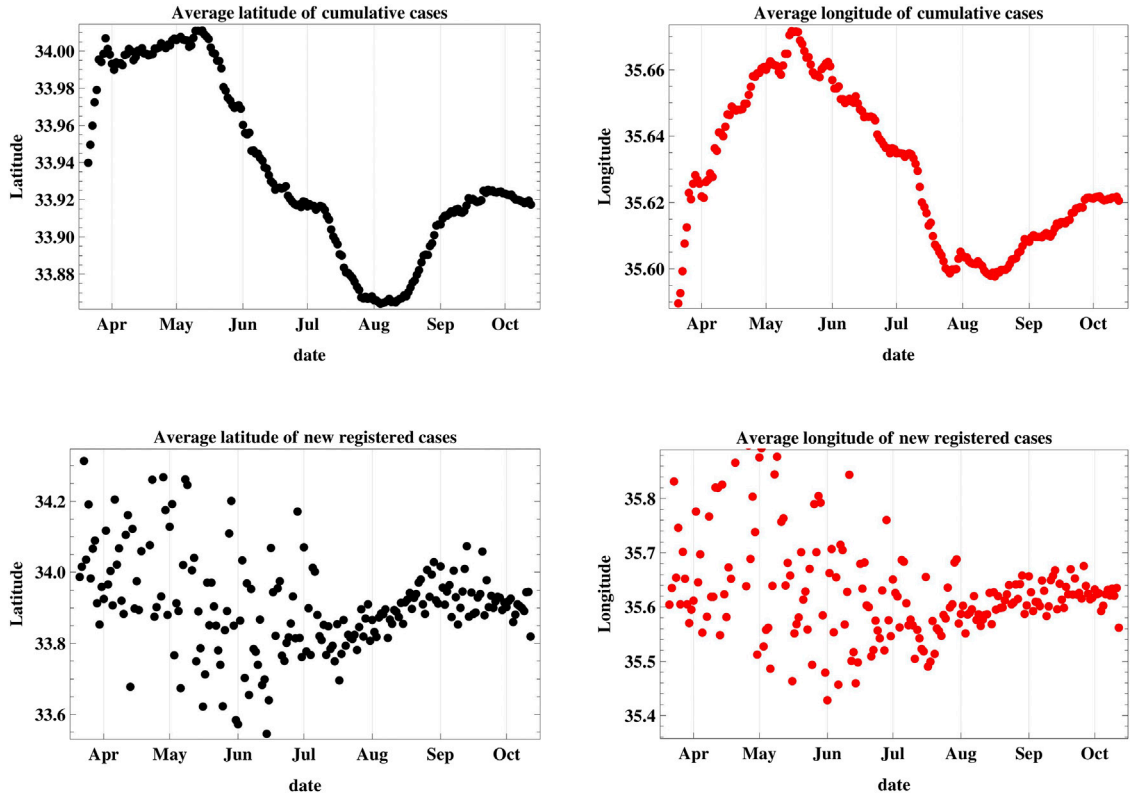

FIGURE 5 | This figure is a plot of the latitude and longitude of the weighted geographic center of COVID-19 infections in Lebanon. The upper graphs represent the temporal progression of the cumulative number of infections while the lower graphs represent that of the new daily cases.

variables) and autocorrelation (spatial structure) [40, 41], and it was not employed in the context of this work, which was based on Moran's univariate statistics.

The location of the MCI was determined as a function of time as shown in **Figure 5**. The mean latitude and longitude of the infection were determined according to the methods described in **Equation 6**. The location of the cumulative MCI is plotted on the geographic map of Lebanon during the same period in **Figure 6**, together with the mean center of population of the country. It started near the city of Jounieh, north-west of the mean center of population, but it has moved southward since May through August, where it started moving northward again. The location of the MCI of new infections was quite geographically distributed before July as the lower plot of **Figure 5** shows, before becoming more homogenous afterward.

The reproduction number R (which has maintained a relatively high rate in Lebanon since June [28, 29]) and the rate of the infection spread correlate with people's mobility [42]. Geographic clustering occurs because people's motion and local travel is higher in their close neighborhoods, especially in a country like Lebanon where with the absence of national public transportation throughout the country [43] diminishes nationwide mobility. Higher levels of social interaction among people in dense regions also contribute to the spread of the disease, and this has shown the strongest clustering effect.

In this study, we employed Moran's I statistics with various parameterizations, in addition to the mean center of infection which is a measure of the centrality of the infections, with its dynamic temporal changes. The two approaches are complementary, and allow us to visualize the dynamics of spread, with its temporal geographical clustering characteristics. In addition, spatial autocorrelation provides unique information about demographic and social characterization of the spread.

Our statistical tests and results correspond to the number of registered cases, which might differ from the actual infections in case of under-reporting, under-testing or in case of asymptomatic infections.

4 CONCLUSION

In this paper we introduced the Moran's I index with its associated z-score and p-value to study the spatial autocorrelation of registered new infections of COVID-19 in Lebanon. We introduced six different cases of parameterization of the spread related to adjacency, proximity, population, population density, poverty rate and poverty density. We discovered that poverty rate is not statistically relevant to the spatial spread of the disease while geographic bordering, distance between district centers, number and density of residents and poverty density lead to clustering of the disease, with varying strengths and level of confidence since July and August through October. We also introduced methods to determine the geographic coordinates of the mean center of the

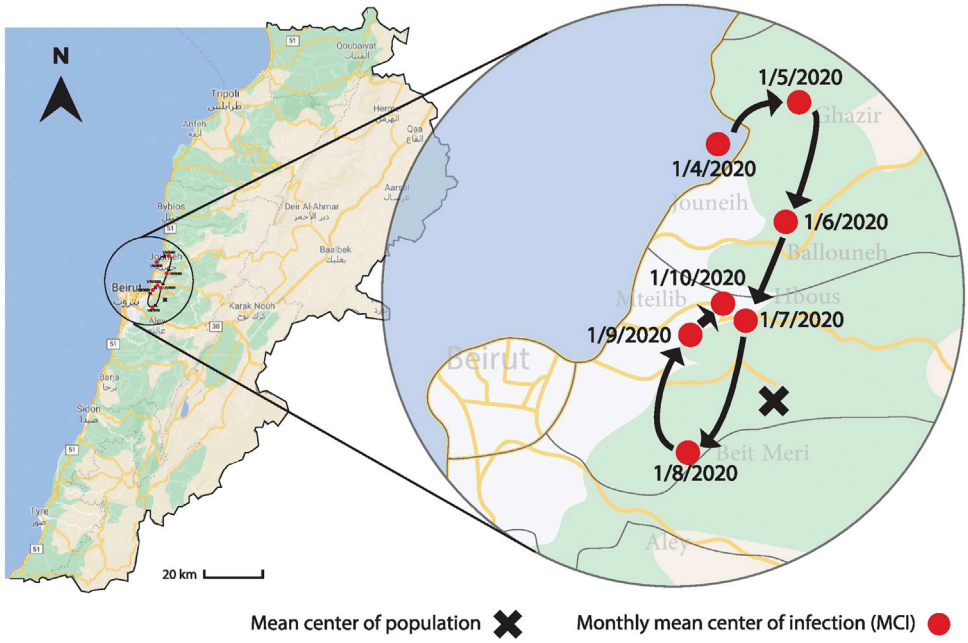

FIGURE 6 | The figure shows the variation of the geographic location of the MCI on a monthly basis between April 1 and October 1, 2020, together with the mean center of the population. The MCI started near the city of Jounieh, north-west of the mean center of population, but it has moved southward since May until August, when it started moving northward again.

infection, and determined this center since April 2020, and plotted its variations over time up until October.

One of the major limitations that prohibit a more detailed analysis is the public unavailability of data on the municipal or sub-district level that would allow a more detailed spatial analysis, and consequently more locally-specific policies and measures to slow down its spread.

The study of the spread of the infection allows relevant authorities to draw appropriate country-specific and regional measures to curb the spread. The understanding of the spatial, demographic and geographic aspects of the disease spread over time provides an essential basis for to take more efficient decisions of local and inter and intra-regional measures, thus contributing to increased social and health safety and security in the fight against the pandemic.

DATA AVAILABILITY STATEMENT

The raw data supporting the conclusions of this article will be made available by the author, without undue reservation.

AUTHOR CONTRIBUTIONS

The author confirms being the sole contributor of this work and has approved it for publication.

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Conflict of Interest: The author declares that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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APPENDIX

The expected value of Moran's I statistic is given by:

$$E[I] = \frac{-1}{N-1}$$

while its variance is defined as:

$$V[I] = E[I^2] - E[I]^2$$

where

$$E[I^2] = \frac{A-B}{(N-1)(N-2)(N-3)\left(\Sigma_{ij} W_{ij}\right)^2}$$

and A and B are given by:

$$A = N\left[2(N^2 - 3N + 3)\Sigma_{ij} W_{ij}^2 - 2N\Sigma_i\left(\Sigma_j W_{ij}\right)^2 + 3\left(\Sigma_{ij} W_{ij}\right)^2\right]$$

$$B = \frac{2\Sigma_i \left(X_i - \overline{X}\right)^4}{\left(\Sigma_i \left(X_i - \overline{X}\right)^2\right)^2}\left[(N^2 - N)\Sigma_{ij} W_{ij}^2 - 2N\Sigma_i\left(\Sigma_j W_{ij}\right)^2 + 3\left(\Sigma_{ij} W_{ij}\right)^2\right]$$

consequently, the z_I-score is given by $z_I = \frac{I - E[I]}{\sqrt{V[I]}}$.

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Precision Regulation Approach: A COVID-19 Triggered Regulatory Drive in South Korea

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COVID-19 has triggered various changes in our everyday lives and how we conceptualize the functions of governments. Some areas require stricter forms of regulation while others call for deregulation. The challenge for the regulatory authorities is to manage these potentially conflicting demands in regulation and define coherently their overall regulatory rationale. The precision regulation approach can be a helpful approach. It is defined here as a streamlined approach to regulation to deliver the right methods of regulation for the right group of people at the right time. This problem-solving innovation in regulation triggered by the recent epidemiologic crisis in South Korea demonstrates the emergence of the precision regulation approach. South Korea has implemented streamlined fast-track services for the biotechnology industry to produce test kits swiftly. This article expands the definition of precision regulation from AI regulation literature, and positions the term as a new regulatory rationale, not as a regulatory tool, using the case study from South Korea.

Keywords: COVID-19, precision regulation, deregulation, biotech industry, South Korea

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INTRODUCTION

Crises drive various changes in our lives. COVID-19 is a global pandemic with 48.5 million cases, and 1,231,017 death confirmed worldwide as of November 6th, 2020 (1). The confining responses of COVID-19, such as lockdowns, quarantine, and self-isolation, have significantly disrupted how we live, work, study, and travel and challenge the norms of what constitutes normality (2). Beyond the everyday routine, the pandemic has broadly impacted legislative reforms and deregulation agendas worldwide; the nations strived to adapt to the needs of government, industry, and civil society under the COVID-19. Regulatory amendements are occurring beyond the medical system to cope with COVID-19 and the post-COVID-19 era.

The level of regulation slides on a binary scale of the regulatory flexibility. The extremities of the binary distinction in regulation, however, may cause public services to be controlled in markets or, conversely, move toward a paternalistic "big brother state" (3). Furthermore, post-pandemic transformations are still unfolding fast and remain uncertain (4). The binary conception of regulation does not leave much room for regulators to adjust after the number of cases dropped. This article highlights an example set by South Koreanbiotechnology industry regulation to illustrate a precision regulation approach, an emergeant regulatory approach to break the binary distinction by combining the deregulation with careful scrutiny. This article aims to expand the concept of precision regulation, which is only applied in technology regulations at present. There

may be benefits for the term to be positioned as a new regulatory rationale beyond a regulatory tool.

THE PRECISION REGULATION APPROACH

The precision regulation approach can thus be defined here as a problem-solving approach to regulation to deliver the right methods of regulation for the right group of people at the right time. It has originated from the term "precision medicine," which is a model that proposes the customization of healthcare, with medical decisions, treatments, practices, or products being tailored to a subgroup of patients, instead of an one-drug-fits-all model (5). In medicine, precision medicine is defined as a healthcare that is finely tuned to each individual. Properly implemented, it has the potential to shift the focus of the health system from the treatment of illness to the protection of health (6). The scholars in the area of precision medicine regulation explicitly claim that "the sector needs to remain adaptive, flexible, and responsive" [(7), p. 299]. Thus, Nicole et al. (7) further suggest that the regulation of such medical model should be based on appropriate consideration of safety, efficacy, cost effectiveness, consistency across geographical, technological and institutional borders, cultural respect, and inclusiveness.

The term "precision regulation" has taken off the field of medicine to be applied to other realms of regulation. IBM Policy Lab also mentions the precision regulation approach for technology in January 2020 to suggest an alternative framework to regulate companies in creating, distributing, or commercializing AI systems (8). The framework details five steps to have trustworthy AI: nurturing an AI ethics specialist; applying an individualized approach to risks, promote transparency among stakeholders; contextualize AI and communicate with regulators; and test for fairness and bias. While the above regulatory rules may be specific to regulating the AI technology, this problem-solving regulatory approach resonates with sectors and governments beyond the AI. Such an application of precision regulation in AI suggest that perhaps the term can be potentially useful for regulators who struggle to find the right balance of regulations post-COVID-19.

BINARY SCALE OF REGULATION: FROM STRICTER REGULATION TO DEREGULATION

The current conceptualization of regulation rests mainly on binary perception. Facing the direct risks of COVID-19, strict spatial confinements were a prominent feature of the earlier phase of the pandemic. As a response to this global disease threat, strict movement restrictions and the travel ban were placed in and out of Wuhan on January 23rd, 2020 (9). Neighboring countries, Hong Kong, Singapore, and South Korea, quickly followed the response, suppressing the disease successfully compared to other countries (10). Despite the delay, European countries came on board, during March 2020, in placing spatial restrictions to prevent further spread of the disease (9).

Strict spatial regulation has been reinforced by technological advancement in epidemiological tracing using mobile apps. They track interactions between those diagnosed with coronavirus and the people they have come into contact with. The purpose of the apps is to effectively identify those who may have contracted the virus that they may not be aware (11). Many countries worldwide, including Singapore, China, South Korea, Germany, Finland, and Australia, have since developed their tracing app or device. When concerns about personal privacy and state surveillance surface, the governments tend to focus more on technological issues and "brushing them aside as unwarranted or paranoia" (3).

On the other hand, there are demands for deregulation that governs economic aspects of lives. Deregulation is intended to increase economic efficiency, raise productivity, and, ultimately, support jobs and wages. As the below accounts illustrate, governments worldwide have identified that deregulation is essential for the pandemic and the post-COVID-19 recovery. For example, regulatory agencies worldwide have issued expedited processes or streamlined regulations for the industry to set up meetings with the agency during the development process for pandemic-related products. In the US, the transportation department has allowed truck drivers to renew their licenses without following standard procedures if they are directly engaged with emergency relief supplies. The government will introduce a slew of tax incentives to spur corporate investment and reshoring, even allowing big companies to run venture capital business by easing the capital investment restrictions for non-financial entities. According to the policy tracker by the IMF (12), the banks worldwide are providing an extension of loans without additional provisioning or downgrades for borrower's credit status or defer loan installments without penalties to ensure the cash liquidity of businesses. The various governments guarantee new bank loans for businesses to cover operating costs during the pandemic (12). Repayment reliefs on mortgages and personal loans to finance housing were announced worldwide. Some countries waive credit card fees and interests, suspend loan interests payment, and extend tenures of trade instruments (12).

However, as the pandemic becomess an everyday reality, regulatory agencies need to review these potentially conflicting demands in regulation to coherently define their overall regulatory rationale. While the changes during the pandemic may be temporary, policymakers will have to decide whether to keep these changes altogether, or return to pre-COVID-19, or select some of the changes. The choices come with trade-offs of values. For instance, streamlining medical product regulation to promote their access can be beneficial in terms of efficiency, affordability, improved health outcomes, and decreased costs to the health care system overall. However, relaxed privacy or data requirements, less frequent inspections, and less scrutinized safety protocols may risk other public values. How do we balance regulations on the binary scale when the contradictions and complications occur in multiple dimensions? The governance of aggregating and shaping the regulatory changes can be a difficult task under a binary scale. The next section describes a regulatory example of South Korea that describes a precision regulation

approach as an alternative way to complement the current binary approach.

SOUTH KOREAN APPROACH IN REGULATION DURING AND POST-COVID-19

South Korea was one of the most severely hit nations in the early days of the COVID-19 outbreak. Following the COVID-19 outbreak, companies in the bio-technology industry were given all the information and support in open competition under emergency fast-tracked approval processes (13). Simultaneous massive public testings reinforced the technologies of biotech companies to attain reliable data, and to improve their inventions. COVID-19 exports of testing kits and personal protection suits increased sharply, uplifting the entire industry and developing treatments, vaccines, and other related areas. The problem-solving nature of regulatory responsesbiotechnology industry in South Korea addressed the regulatory risks in timely fashion to have rapid COVID-19 test kit development.

The Korean Center for Disease Control (KCDC) used emergency fast-track procedures to promote COVID-19 test kits (13). Infectious disease experts in the public and private sectors were called into frequent and urgent task force meetings to devise protocols to engage industry partners in developing the test kits. Appropriate incentives were provided and full transparency of the publicly held data and test methods on the disease. The KCDC considered the fact that initial test kits might not be of high quality, given the limited time for development. The Korean Society for Laboratory Medicine (KSLM) was the key actor in enabling laboratory preparedness and responsiveness for the quality and robustness testing of the test kits. The KSLM also contributed inmaintaining diagnostic testing quality for prototype test kits by providing unbiased validation sites and procedures (14). More than 2,723,960 people had been tested by November 10th (15). This in turn, allowed the biotech industry to share large samples to improve on the test kit accuracy. Korea conducts up to 15,000–20,000 tests a day, with the remainder exported to other countries.

Hence, the precision regulation approach in this case studyhas two critical characteristics: (i) embracing the urgency of the problem in regulations and (ii) involving plural actors to effectively resolve the problem. However, addressing the regulatory problem promptly while upholding quality standards is not an easy task and can be very costly. Indeed, the prerequisites for the precision regulation are likely to be reasonably well-established public health infrastructure, high level of inter-agency trust, and efficient intersectoral communication skills among the policy actors. Those characteristics helped to accelerate the discussions and enable feedback mechanisms to expedite the political processin the South Korean case.

Nonetheless, creating opportunities for discussion and negotiating ways forward has not been the traditional task for policy designers (16). The notion of "polycentric governance" (17), captures an increasingly complex and diversified political landscape in which many actors draw on various forms of material and symbolic power to influence decision-making processes and outcomes. The understanding of polycentricity of the precision regulation approach situates itself in the stream of regulation literature[1] emerged to focus on innovative approach to achieve compliance, including "responsive regulation" (18), "nodal governance" (19), "steering-at-a-distance" (20), "smart regulation" (21), and "meta-regulation" (22) and Meta-governance (10). The strength of these approaches is that they recognize that the capacity to deliver on regulatory objectives lies primarily with those regulated, rather than those who regulate. The concepts highlight the polycentricity of the regulated actors, contributing to breaking the binary conception of the regulation.

The binary approach to regulation looks at the regulation functioning like a flip switch that turns either on or off (23). This approach may have limited insights into the behavior of the industry actors to the policies and regulations. Suppose, for instance; a dichotomous deregulation approach was taken for the bio-technology industry. In that case, the future regulator has to face the impacts of the changed behavior, practices, and outcomes of the industry actors, which may be low-quality products, moral hazard, and public dependency of the private sector. In the South Korean case, in order to prevent potential pitfalls, precision in regulations was emphasized. The regulatory steps were scrutinized to ensure that the deregulation does not suffer from the future costs for the regulator and the industry. That is the way the government needed to include a variety of actors in the regulatory process. The rapid feedback mechanisms enabled polycentric governance through the regulatory precision approach.

Based on the case study, the precision regulation for the pandemic can be used to reinforce meta-governance with the explicit goal of public value delivery. For the case of deregulation, effective regulation should aim to satisfy political expectations and operational feasibility (24). Precise and targeted deregulation in the bio-technology industry and effective communication in public-private regulatory partnerships have been South Korea's critical enablers of COVID-19 test kit development (13). Furthermore, the industry experts and private sector medical practitioners played crucial parts in testing and validating test kits in the streamlined processes. The sense of urgency to achieve such challenging goals further necessitated the involvement of wide spectrum of actors to join the discussion.

CONCLUSION

This article identifies the precision regulation approach, using the case study of biotechnology industry regulation in South Korea. The regulatory approach worldwide is primarily divided between flexible arrangements and deregulation, depending on the sectors and the urgency created by the disease. The article points out that such binary understanding of regulation may fall short of

[1]The literature's primary focus is on regulation in pursuit of public regulatory goals, which will often imply regulation by public regulatory bodies, which may of course involve the mobilization of private actors, civil society, and public-private partnerships.

adequately addressing the wide spectrum and the interconnected aftermath of the pandemic. It may be too soon to declare South Korea's regulatory approach as precision regulation because the regulatory responses continue to evolve as the battle against COVID-19 continues. Nonetheless, the South Korean COVID-19 regulatory response on the biotechnology industry can guide other nations struggling to balance the binary scale of regulatory flexibilities. The essence of the South Korean case is the focused attention on the specific problem, striving to incorporate multiple aspects of the problem, and an active engagement between private and public sectors, which can be intuitively applied to various countries. Furthermore, future studies may find more examples of the precision regulatory approach in countries with relatively higher quality of public health infrastructure and high inter-agency trust. It may be timely for scholars worldwide to discuss the new rationale for regulation in post-COVID-19 governance.

DATA AVAILABILITY STATEMENT

The datasets presented in this study can be found in online repositories. The names of the repository/repositories and accession number(s) can be found in the article/supplementary material.

AUTHOR CONTRIBUTIONS

SL and WK have contributed equally to the conceptualization of the article. SL has drafted the article. WK added his insights. SL and WK revised the article together. Both authors contributed to the article and approved the submitted version.

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Conflict of Interest: The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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Transparency in Negotiation of European Union With Big Pharma on COVID-19 Vaccines

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INTRODUCTION

Immunization through vaccination represents one of the most cost-effective public health interventions and the main tool for primary prevention of communicable diseases. Vaccination programs and vaccine prices, however, vary considerably among and within countries in the European Union (EU), because of the differences in the way healthcare systems are organized at the national or regional levels. These differences may lead to a new threat represented by the so-called "vaccine nationalism" that keep negotiations with the pharmaceutical industry behind the closed doors of each single nation, thus undermining global efforts to ensure fair access to vaccines for everyone (1). The severity of the recent COVID-19 pandemic is urging a major change in our capabilities to respond in the most appropriate and coordinated manner to the emergency situation. Transparency about the different roles of all stakeholders, either public or private, of vaccine manufacturers, and of health authorities and, most importantly, transparency in negotiations regarding vaccine price, could help avoid misconceptions, thus strengthening the collaboration required to protect against the pandemic.

VACCINE PRICE

New vaccine pricing is a complicated process, including target population analysis, mapping of potential competitors, quantification of the incremental value, determination of the vaccine positioning in the marketplace, assessment of the vaccine price-demand curve, calculation of the costs of manufacturing, distribution, research and development, and inclusion of the various legal and regulatory expenses (2). The effective final price of the new vaccine may, eventually, be different for different purchasers because of various discounts, promotions, and incentives that the manufacturers may apply considering geographic and economical situations, as well as different times of the year, especially for flu vaccines (3). Transparency in the negotiation for vaccine prices has been a matter of debate for many years. In 2014, WHO launched the vaccine product, price, and procurement initiative, named Market Information for Access to vaccines (MI4A), aimed to improve vaccine price transparency (4). Thanks to the database created by the MI4A and improved price transparency, many low- or middle-income countries increased their possibility to access information, their capacity to negotiate affordable prices and strengthen their access to affordable vaccines (5). However, the issue is still far from being resolved.

THE LESSON (UNLEARNED) FROM FLU VACCINE

The emergence and subsequent global spread of the 2009 A(H1N1) influenza, also known as swine flu, with nearly 2,000 deaths in the EU, prompted health authorities around the world to review their response and to improve the reaction to the pandemic. During the 2009 pandemic, vaccine manufacturers greatly increased influenza vaccine production capacity and adopted a "tiered-pricing" strategy, where the price of a vaccine was mainly based on the level of income of the country (6). At that time EU member states struggled to obtain sufficient quantities of vaccines as quickly as needed and had to accept unfavorable contractual terms (7). The most developed countries placed large advance orders for the 2009-H1N1 vaccine and bought virtually all of what the vaccine companies could manufacture. National interests clearly prevailed over global solidarity. Wealthier governments that had provisional contracts with vaccine makers monopolized the global vaccine supply. By means of such contractual obligations, manufacturers committed all their capacity to produce and deliver vaccines to those who could pay the most (8). As a result, the 2009-H1N1 vaccine production affected the amount and timing of vaccines available for developing countries. Even though WHO entered talks with manufacturers and developed-country governments to secure some vaccines for developing countries through monetary donations both from manufacturers and developed countries, such donations still left the developing world with limited supplies or the vaccines arrived too late to be of much benefit. However, the impact of the H1N1 virus was less severe than anticipated, and health authorities of many countries had to face the problem of stockpiles of unnecessary swine flu vaccines. They had to negotiate with manufacturers over the suspension of delivery for surplus vaccines, and they tried to sell or donate at least part of them. The experience with previous pandemic flu prompted the manufacturers and the health authorities to work together to enhance global access, and to strengthen future preparedness. In 2018, a multidisciplinary expert panel was invited by the EU to identify measures and actions to improve vaccination coverage and to encourage close cooperation and better integration of public health and primary care services among member states in the EU[1]. Among the changes proposed, there were some crucial scientific and technical improvements to rapidly select optimal vaccine viruses, actions to speed up vaccine production, and instruments to implement vaccine supply by means of the establishment of appropriate agreements prior to a pandemic.

However, was that experience useful in improving our ability to combat the actual COVID-19 pandemic? Are we facing a replay of the past H1N1 influenza pandemic of 2009, with wealthy countries hoarding the vaccines? A concern was raised regarding transparency of the different roles of all stakeholders and about price, liability, and availability of vaccines. Full transparency of the vaccines' contracts, as well as the publication of clinical trials data before marketing authorizations are granted, is requested and this represents the key to widespread use of potentially life-saving vaccines.

[1]http://ec.europa.eu/health/expert_panel/index_en.htm

THE COVID-19 PANDEMIC

The global COVID-19 pandemic has stricken the EU with almost 17 million people infected and more than 400,000 deaths as of data obtained on week 1 of 2021 by the European Center for Disease Prevention and Control. There is a global request for a safe and effective vaccine against COVID-19 (9). The urgency to manufacture and to make accessible to everyone a successful COVID-19 vaccine prompted the EU to promote a common strategy (EU Com. n. 2020/245). In this regard, the COVID-19 pandemic is accelerating the interdependence of all EU economies and societies to form a closely integrated single market, as indicated by the 8th President of the EU commission, Jacques Delors, who launched this program in 1985, allowing a joint action at EU level on health policies, including the market for drugs and vaccines. This represents an excellent opportunity to be one step closer toward the unification of the different national health policies, thus eliminating unjustifiable functional duplications between the European Medicines Agency (EMA) and every single national drug agency, at least regarding negotiation procedures.

THE EU STRATEGY FOR COVID-19 VACCINES

According to the program for the years 2014–2020, the EU's action in the field of health was to complement and support national health policies, encourage cooperation, and promote coordination between their programs, in full respect of the responsibilities of each single member state for the definition of their health policies and the organization and delivery of health services and medical care (EU Reg. n. 2014/282). Following the unprecedented public health emergency created by COVID-19, the EU has modified the previous choice of not defining any specific health policies, and a range of measures have been taken by the EMA and by a network of national competent authorities to facilitate, support, and speed up the development and marketing authorization of treatments and vaccines (EU Reg. n. 2020/1043). A new program, named the EU4Health program, has been approved for the years 2020–2021, with the aim of strengthening the EU's role on health, and its capacity to react, manage, and coordinate its powers by means of a "European Union of Health" (EU Com. n. 2020/405). The new EU strategy for COVID-19 vaccines was presented in June 2020 (EU Com. n. 2020/245). It consisted of three objectives: (i) ensuring the quality, safety, and efficacy of vaccines; (ii) securing timely access to vaccines for member states and their population, while leading a global solidarity effort; and iii) ensuring equitable access for all to an affordable vaccine as early as possible. Such a strategy focused on the production and on the procurement of sufficient doses of vaccines for each member state, through Advance Purchase Agreements (APAs) negotiated with vaccine producers. Legal instruments to support such emergency action

were established in 2016 (EU Reg. n. 2016/369) and amended in 2020 (EU Reg. n. 2020/521). Based on the considerable legal and practical difficulties in purchasing supplies or services in emergency situations by the contracting authorities from each member states, the EU commission extended its possibilities to purchase supplies or services on behalf of them and advocated the authority to directly negotiate for the purchase of health supplies and, particularly, of COVID-19 vaccines, to get maximum benefit in terms of economies of scale and risk–benefit sharing.

THE EU POSITION ON TRANSPARENCY WHEN NEGOTIATING ADVANCE PURCHASE AGREEMENTS

According to these emergency regulations, a number of derogations from previous articles have been set out and applied for a limited period of time, from February 1, 2020 until January 31, 2022. In no document, however, was a derogation from the transparency on negotiations of APAs for COVID-19 vaccines reported. In a statement to the plenary of the EU Parliament on transparency of purchase as well as access to COVID-19 vaccinations, released by Mrs. Stella Kyriakides, commissioner on health and food safety, it was reported that "*vaccinations, once we have a vaccine which is proven safe and effective, will play a crucial role: in saving lives, in containing the pandemic, in protecting health care systems, in helping to restore our economy*" (statement by Kyriakides, 12.11.2020). The EU commission has worked intensively to have a common EU portfolio of different vaccines against COVID-19 as diverse as possible. Many APAs have already been signed with *Johnson & Johnson, AstraZeneca, Sanofi-GSK, Janssen Pharmaceutica NV, BioNtech/Pfizer, CureVac, and Moderna*. To date, the commission has secured at least 1.2 billion doses and has fulfilled its commitment of ensuring equitable access to "*safe, effective, and affordable vaccines*." It appears clear that such a huge number of doses will represent a relevant cost for the EU health system, and negotiations for the price of each single vaccine is a significant matter of debate. Following the EU commission negotiations, the Italian ministry of health has launched its vaccine strategy plan aimed to ensure 202.5 million doses for all Italian people (strategic plan for vaccine anti-SARS-CoV-2/COVID-19, updated on 15.12.2020). Centralized negotiation procedures have obvious advantages; however, they demand transparency, especially when they involve huge public financial resources. It is therefore expected that the EU commission maintains a high level of accountability and transparency, and it is reasonable to ask what procurement rules are being followed and how the professionals involved were recruited. In her statement Mrs. Stella Kyriakides recognizes the importance of transparency. However, she admits that "*due to the highly competitive nature of this global market, the commission is legally not able to disclose the information contained in the contracts.*" It is a special request by the companies, in fact, that "*such sensitive business information remains confidential between the signatories of the contract.*" The commission, therefore, cannot decide to unilaterally disclose the terms of negotiation without the consent of all involved parties.

THE POSITION OF THE PHARMACEUTICAL COMPANIES

There are many requests, coming from several different sources, directed to the pharmaceutical corporations to open their books to show the economic aspects of the contract, the costs of vaccine production, and how much the countries agreed to pay for each vaccine type. The major concern is that wealthy countries could buy up huge amounts of vaccine stocks, leaving poorer countries facing huge difficulties to afford what they need. The major pharmaceutical companies, represented by the International Federation of Pharmaceutical Manufacturers and Associations (IFPMA) and by the European Federation of Pharmaceutical Industries and Associations (EFPIA), respond that they are committed to working with governments, partners, and payers to ensure that vaccines will be available and affordable for people at a fair and reasonable price. In addition, following the EMA initiative, they issued a joint pledge promising to implement extraordinary transparency measures in the context of COVID-19 (10). Such measures include speeding up the publication of key documents, accelerating the announcements of drugs included in the compassionate use programs, implementing earlier deadlines for publishing public evaluation reports, publishing the complete version of the management plan as well as the clinical trial data, while also protecting privacy rights. Although such an initiative will undoubtfully have advantages in transparency for healthcare professionals, researchers, media, policymakers, and the general public, they are focused on regulatory processes and procedures for patients, and contain no mention concerning transparency in the negotiation procedures. According to the pharmaceutical companies, non-disclosure clauses are a standard feature in APAs. They are necessary to protect sensitive negotiations and business-related information, including financial information, development, and production plans. The two pharmaceutical companies *Moderna* and *Pfizer* do not hide that they would be making a profit on their vaccines. *Pfizer* CEO Albert Bourla said to Barron's magazine in July 2020 that since the private sector found the solution for diagnostics and, again, since the private sector found the solution for therapies and vaccines, it is wrong to think that the private sector should not be making a profit on the drugs and vaccines they introduce to fight COVID-19 (11). This is frustrating when we consider that there is a huge amount of public investment behind the contracts for COVID-19 vaccines. This may represent a huge privatization of public money. On the other side, *Johnson & Johnson* and *AstraZeneca* indicated that they would sell vaccines at their cost through the pandemic. Recently, *Johnson & Johnson* announced an agreement in principle with the Global Alliance for Vaccines and Immunization (GAVI Alliance) to supply *Janssen*'s COVID-19 vaccine to lower-income countries in 2021 (12). *Glaxo* and *Sanofi* also declared that they do not expect to profit during the pandemic phase (13).

TRANSPARENCY IN THE NEGOTIATIONS FOR COVID-19 VACCINES

By advocating the authority to directly negotiate for the purchase of health supplies and, particularly, of COVID-19 vaccines, the EU derogated from this previous commitment to respect the responsibilities of each single member state for the definition of their health policies. This is justified by the emergency created by the COVID-19 pandemic. However, should transparency on negotiations for COVID-19 vaccines be derogated as well? Why has the commission accepted to be legally bound to secrecy and decided to forgo its duties in accountability and transparency to the people it is supposed to serve? Have all the potential long-term consequences of this secrecy on the EU pharmaceutical market been considered, and on what basis was it decided to accept this secrecy using public funds without seeking public consent? Vaccine pricing differs widely among countries, and a global approach has been advocated to guarantee that all subjects can be vaccinated, especially those of low-income countries (14). Many relevant concerns have been raised about the new COVID-19 vaccines (15). We believe it is relevant to answer another key question: Is transparency in the negotiations of health products still a priority issue? It certainly was in 1988, when the EU council mandated a specific directive on this topic (L40/8, 89/105/EEC). In 2018, WHO published its draft road map for access to medicines, vaccines, and other health products 2019–2023, encouraging exchanges of information and knowledge among different countries and supporting a global and regional collaboration to increase price transparency for quality-assured health products (WHO, 144th session, Provisional agenda item 5.7, EB144/17). Transparency in the negotiations on COVID-19 vaccines has been advocated by many (16, 17). One of the most active medical humanitarian organizations, Médecins Sans Frontières, requested both transparency on how public money is handed over to pharma corporations (18) and recommended accessibility with equity for everyone who needs COVID-19 vaccines. The international non-governmental organization Human Rights Watch focused attention on "opaque" vaccine deals that could undermine the global recovery from the pandemic and claiming that "health not wealth" should determine access to a COVID-19 vaccine. The transparency issue was raised again in 2019, at the 72nd World Health Assembly, in Geneva by former representatives of the Italian Ministry of Health and the former director general of AIFA, Dr. Luca Li Bassi, in a resolution for transparency when negotiating drug prices (WHA Doc. 72.8/2019). The aim was to promote reforms in national, European, and global frameworks to make quality medicines, vaccines, diagnostic tests, and new medical technologies and therapies available and affordable. For his work, Li Bassi was awarded the 2019 "International Transparency in Medicines Policies Awards" by the French Civil Society watchdog group l'Observatoire Médicaments Transparences (the Observatory for Transparency in Medicines). Another step ahead toward transparency on negotiation for COVID-19 vaccines was recently made by the Brazilian public research institution, Fundação Oswaldo Cruz (Fiocruz), who disclosed the terms of its agreement with *AstraZeneca* for the production of a potential future COVID-19 vaccine[2]. Despite all these initiatives, transparency in the EU negotiation of the COVID-19 vaccines is still lacking. Recently, even members of the EU parliament (MEPs) called for more clarity and transparency on COVID-19 vaccine contracts and asked to grant access to all the APAs for COVID-19 vaccines. Therefore, even MEPs do not have access to the most basic information, such as: how much will the production of these vaccines cost? and what will be the liability of the companies for any damage caused by a vaccine? A partial positive response was given by Mrs Sandra Gallina, the EU's lead negotiator on COVID-19 vaccine contracts. She opened a dedicated "reading room," that currently only contains the contract with *CureVac*, to allow a select few MEPs to review the redacted versions of the contract, signed with companies. We believe that this is not enough, and persistence of secrecy in legal agreements by the EU and vaccine manufacturers represents a barrier to global equitable COVID-19 vaccine access and distribution (19). We, therefore, support the request, recently posted by 39 civil society organizations, including the European Public Health Alliance, and directed to the EU commission and to the EU national governments to ensure a maximum degree of transparency in the EU's exchanges, negotiations, and deals with pharmaceutical companies over COVID-19 vaccines[3].

COVID-19 VACCINE PRICE LEAKS

In December 2020, documents relating to COVID-19 vaccines and, in particular, to one from *Pfizer/BioNTech* were stolen from the EMA agency, which, after Brexit, is located in the Netherlands. EMA confirmed the cyber-attack, and criminal investigations are ongoing to clarify whether the stolen data are up for sale or if they have been published for anyone to access.

However, this is not only a case of leaking information regarding COVID-19 vaccines. The COVID-19 vaccine prices that the EU commission kept secret and covered by "confidentiality" were released via Twitter, seemingly in a blunder, by Belgium's budget state secretary, Eva De Bleeker. She tweeted the price of all the COVID-19 vaccines that the EU had negotiated with pharmaceutical companies on behalf of its 27 member states, with the list of the country's number of vaccines and the price they were paying per each dose. The tweet was quickly removed, but the list had already been made public, and it was reported by the New York Times (20). The pricing data contained in the list were not confirmed by the EU spokesman, who declared that the secrecy about the prices paid by the EU is legitimate and is part of the negotiation for the vaccine. It is likely that such information on COVID-19 vaccines prices will influence future negotiations with manufacturers. According to such leaked information, the United States, who

[2]https://agencia.fiocruz.br/sites/agencia.fiocruz.br/files/u34/contrato_etec.pdf
[3]https://epha.org/wp-content/uploads/2020/12/jointtransparency-statement-final.pdf

FIGURE 1 | Transparency in the negotiations for Advance Purchase Agreements (APAs) on COVID-19 vaccines. The EU is coordinating a joint effort to secure the acquisition of a sufficient quantity of COVID-19 vaccines in the EU through Advance Purchase Agreements (APAs) with vaccine producers, but transparency in negotiations is lacking, and sensitive business information remains confidential between the signatories of the contract.

negotiated prices and arranged to buy doses for every American directly, is paying more than Europe. In any case, it is relevant to mention that during these days, all the hospitals that operate in the United States have been required to comply with the centers for medicare and medicaid services' price transparency requirements detail, so-called "the Rule." They are required to make public a list of their standard charges for the services they provide[4]. According to COVID-19 vaccine policies and guidance, "the Rule" also includes the price of COVID-19 vaccines, not only for medicare but also for medicaid services as well as for private insurance.

CONSEQUENCES OF THE ABSENCE OF TRANSPARENCY ON COVID-19 VACCINE NEGOTIATIONS

The absence of transparency on the negotiation for COVID-19 vaccines frustrates attempts to unify all EU member states into a single market and leaves many countries competing against one another for a better offer, for the overall number of vaccine doses distributed or for the right of first choice. Maintaining a high level of transparency is crucial to reinforce trust in the overall handling of the pandemic by the EU and by every national government, to ensure confidence in vaccines and to minimize skepticism, doubts, and suspicion. In addition, a lack of transparency may increase the risk of corruption. In this regard, António Guterres, the secretary-general of the United Nations, reported in a statement that the COVID-19 pandemic is creating new opportunities for corruption, and inadequate transparency may further increase such a risk (21). Transparency in negotiations as well as equity in global health issues should return to represent priority issues for both the EU and WHO, to avoid deplorable asymmetries in access to information, proliferation of bilateral APAs, entrenching nationalism, and directing future vaccine distribution, especially during the negotiations for the most profitable business ever: the one of COVID-19 vaccines (**Figure 1**). Full transparency in negotiations with the pharmaceutical companies will contribute to guarantee the success of the EU's mass COVID-19 vaccination campaign.

AUTHOR CONTRIBUTIONS

SS wrote the article and AB revised the text. All authors contributed to the article and approved the submitted version.

[4]https://www.federalregister.gov/documents/2019/11/27/2019-24931/medicare-and-medicaid-programs-cy-2020-hospital-outpatient-pps-policy-changes-and-paymentrates-and

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Socio-Economic Implications of COVID-19 Pandemic in South Asia: Emerging Risks and Growing Challenges

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The dramatic spread of COVID-19 has threatened human lives, disrupted livelihoods, and affected trade, economy and businesses across the globe. The global economy has begun to show major disruptions and is heading toward a severe recession with an unprecedented economic crisis. As the global economy is highly integrated and interdependent through the global supply chains, it has been profoundly affected by the COVID-19 pandemic. Although all countries have faced difficulties due to Covid-19, South Asian countries in particular have had to deal with a more challenging situation due to their large population, weak health facilities, high poverty rates, low socio-economic conditions, poor social protection systems, limited access to water and sanitation, and inadequate living space, necessary to maintain physical distancing and take other required measures to contain this pandemic. To contain the spread of the virus, South Asian countries have imposed stringent lockdowns, which have consequently affected the lives and livelihoods of millions of people in the region, where a third of world's poor live. Against this backdrop, this paper examines the existing and prospective impacts, risks and challenges of Covid-19 on key social and economic sectors including migration, tourism, informal sector, agriculture and rural livelihoods. The analysis revealed that COVID-19 is likely to affect economic growth, increase fiscal deficit and monetary burden, increase the risks of macroeconomic instability, decrease migration and remittance, reduce income from travel and tourism, and result in dwindling micro-small and medium industries and informal businesses. This is likely to deepen poverty and increase unemployment and the risks of hunger and food insecurity. If not addressed properly, this may reinforce existing inequalities, break social harmony, and increase tension and turbulence. The economic and social costs of the COVID-19 outbreak are therefore likely to be significant and long-lasting in South Asia.

Keywords: COVID-19, socio-economic impact, public health, Poverty and inequality, South Asia

INTRODUCTION

The escalating spread of COVID-19 has posed the gravest threat not only to the world economy but also to lives and livelihoods. What started as a health shock has now been transformed into a global economic crisis. In a heavily globalized and interconnected world, this has translated into a state of unparalleled economic recession (Ozili and Arun 2020). COVID-19 has become a global systemic economic risk as it has affected almost all the economies of the world, no matter how small or large they are. Because of high globalization, economic integration and interconnectedness among the different sectors of economy, a change in any part of the economy or any country now affects other sectors of the economy in other parts of the world as well. Like climate change, pandemics are now global risks as it can spread around the world quickly, regardless of where it originates (Acharya and Porwal, 2020; Ibn-Mohammed et al., 2020).

COVID-19 has posed unique challenges to the South Asian economies due to the region's large population and high rates of poverty, deplorable health infrastructures, poor socio-economic conditions, inadequate social protection systems, limited access to water and sanitation facilities and inadequate living space arrangements (Rasul, 2020; Hossain, et al., 2020). South Asia is one of the poorest regions in the world: about one-third of the world's poor live in this region with about 70 per cent living in rural areas and primarily dependent on agriculture. Before the COVID-19 pandemic, 649 million people in South Asia were moderately or severely food insecure and 271 million were severely food insecure. Similarly, 36 percent of the children were stunted and 16 percent were acutely malnourished. The situation is likely to worsen further due to the effect of COVID-19 (Rasul, 2020).

The world's many megacities such as Delhi, Mumbai, Karachi and Dhaka are in this region and their population density is extremely high. In many countries, people lack access to basic services such as clean water, sanitation and hygiene facilities. For example, close to 42% of households in Afghanistan are compelled to use unsafe drinking water and more than 50% do not have access to water and soap to wash hands (ICIMOD, 2020). Furthermore, high population density, poor working conditions and inadequate living space make social distancing very difficult. The world's largest slums are in South Asia and many of these are home to huge numbers of people, for example the Orangi area in Karachi, Pakistan (2.5 million), Dharavi in Mumbai, India (1 million), and the Rohingya camps in Cox's Bazaar, Bangladesh (about one million) (Rasul, 2020). These overcrowded living spaces and limited, and often shared, water and sanitation facilities have made physical distancing and self-isolation difficult, consequently increasing the risks of exposure and vulnerabilities (Hossain, et al., 2020). Because of the already strained economic conditions, the majority of the people in this region have few resources and weak capacity to cope with the exposures of a pandemic shock. The challenges are reinforced by the fact that a large share of population make their living through informal sectors or self-employment, without any health or social protection (ICIMOD, 2020).

Being concerned with the fast spread of COVID-19, a few scholars, particularly in India, have made efforts to understand the nature dynamics of the COVID-19 pandemic to model and forecast the pace of transmission and rates of mortality (Khajanchi and Sarkar, 2020; Samui et al., 2020; Khajanchi et al., 2020). Similarly, Acharya and Porwal (2020) have also assessed whether the population's vulnerability of being infected and the rates of mortality due to the infection depend on the demographic composition of the population in the different states of India. All these studies emphasized the need for maintaining physical distance and contract tracing to control the spread of the corona virus. Realizing the importance of maintaining physical distance, the governments of this region have imposed strong lockdowns to save people's lives.

Although South Asian countries have been relatively successful in containing the spread of the virus and saving people's lives in the early months of the pandemic (both infection and loss of lives are relatively low in South Asia compared to many developed economies), the success has come at a high economic cost due to extended lockdowns which directly impacted economic activities. Simulation results suggest that lockdown of any economy for a month might result in an annual GDP loss of 1.5%–2.0%. It is estimated that the Indian economy incurs a loss of US$ 4.64 billion for locking down the economy for a single day (Acuité Ratings, 2020).

South Asian countries have poor health care systems. Afghanistan has only 2.8 physicians per 10,000 people, Bhutan 3.8, Bangladesh 5.3, and Nepal 6.5, a 10th of the number in more advanced countries. Even India, which has one of the strongest health systems in the region, has only 7.8 physicians per 10,000 people (Rasul, 2020). The South Asian countries, due to weak health facilities and resources, have taken very stringent policy measures to contain the spread of the corona virus and save people's lives. Except a few essential services, the economic activities have shutdown, travels are banned, movement of goods and services are restricted and cross-border movements are closed. Labor, the main factor of production, has been quarantined, borders have been closed and national, regional and global supply chains have been disrupted mostly in the South Asian region.

While the current policy measures of physical distancing and lockdown are critical for saving people's lives and in combatting the spread of the corona virus, these measures have affected the lives and livelihoods of millions of people in the South Asian region, which is home to one third of world's poorest population (ESCAP, 2020). The stronger the lockdown, the greater the economic impacts are. In this backdrop, this paper briefly examines the following questions: What are the existing and prospective economic impacts of COVID-19 pandemic in South Asia, what are the challenges and issues faced by the poor vulnerable population, and what are the likely impacts in the near future—short, medium and long-term? How the economic sectors like, migration, tourism, the informal sector, and agriculture and rural livelihoods will be affected by this pandemic? What are the key measures and actions taken by South Asian countries to address these challenges? What policy

TABLE 1 | Measures taken by the Governments in South Asia to contain spread of COVID-19 in early stage of infection.

Country	Lockdown measures (duration)	International borders/travel restrictions	Air travel	Land transport	Maritime transport
Afghanistan	Complete lockdown from 22 March till 24 May	Closed, open only for immigrants	Passive restriction enforced by neighbor countries at border	Passive restriction enforced by neighbor countries at border	Not applicable
Bangladesh	Started from 26 March to 16 May and extended further to May 30. Hotspot lockdowns imposed	Closed	Domestic flights opened from 1st June. International flights closed till 15th June. Cargo flights only	Freight trains	Essential good only
Bhutan	Restriction on entry of tourists from 6 March; 23 March—international borders sealed lockdown from April 1 to 21	Closed	Not allowed	Essential goods only	Not applicable
India	25 March to 31 May lockdown extended till 30th June in containment zones. Many activities were allowed after June 8, 2020	Closed	Domestic flights resumed but passive restrictions for international flight	Passive restriction enforced by neighbor countries at border	No data
Maldives	Public health emergency was declared on 19 March. Lockdown from 1 April to 12th June in greater Malé	Closed	Permission required	Not applicable	Allowed
Nepal	23 March to 2 June. Further extended to 14 June	Closed	Permission required	Conflicting information	Not applicable
Pakistan	1 April to 9 May. lockdown lifted	Closed	International flights allowed cargo flights only	Prohibited	Allowed
Sri Lanka	Public holiday declared from 15 March lockdown from 20 March to 11 May	Closed	Cargo flights	Prohibited	No data

Sources; Adapted from UNESCAP, 2020.

responses are needed by national, regional and global communities to address these challenges?

The paper is organized as follows. After this introduction, *Economic Impacts of COVID in South Asia* assesses the macro-economic impacts of COVID in South Asia, particularly on vulnerable economic sectors. *Emerging Social Risks and Vulnerabilities*, examines the cascading effects and emerging social risks and vulnerabilities. *Emerging Opportunities* discusses emerging opportunity to use the disruptive forces of the COVID-19 pandemic and the associated policies for recovery. *Government and Civil Society Responses*, discusses government responses and the final section of the paper draws a conclusion and suggest policy measures that are required to address these challenges.

ECONOMIC IMPACTS OF COVID-19 PANDEMIC IN SOUTH ASIA

South Asian countries took various stringent measures to contain the spread of COVID-19**.** Key measures undertaken by different countries included closure of offices, restaurants, hotels, schools, colleges and education institutions, international borders, suspension of visas, imposition of complete international and domestic travel bans, and ban on public gatherings (**Table 1**). While these measures significantly helped control the coronavirus spread in South Asia, they also imposed huge economic and social cost at the society. Tourism, exports and remittances, which are important sources of foreign exchange earing for South Asian countries, have also been affected significantly. South Asian economies are likely to shrink for the first time in 4 decades (IMF, 2020). This section summarizes key socio-economic impacts that South Asian countries faces due to the Covid-19 pandemic.

Increasing Risks of Macroeconomic Instability

***Declining GDP growth*:** While the pandemic is still developing and the actual economic impact has yet to be fully known, different forecasts suggest that the South Asian countries will experience the worst economic performance in the last 40 years due to COVID-19. The magnitude of the economic impact will depend upon the duration and severity of the health crisis, the duration of the lockdown, and the manner in which the situation unfolds once the lockdown is lifted. As per the International Monetary Fund's forecast, the overall GDP growth rate for the South Asian countries is expected to be in the range of -18% (Maldives) to 3.8% (Bangladesh) in 2020, where five countries are expected to have negative growth trajectory (**Table 2**). A sharp fall of GDP or negative growth of GDP means that a significant part of the population would lose income during 2020. While population is growing and inflation is raising (**Table 1**), the reduction in GDP means that the per capita income will decline further, which will affect the livelihoods of the general public. If the global economy recovers rapidly, the South Asian region is also expected to have better growth prospect in 2021, where Maldives is expected to lead the region with 12.7% growth followed by India (8%).

Declining trade volume: COVID-19 has severely disrupted international and regional trade and supply chains (Baldwin and Tomiura, 2020). Many countries have temporarily closed their borders, reduced or halted non-essential imports, and canceled import orders from other countries. South Asian countries'

TABLE 2 | Macro-economic indicators of South Asia -Real GDP Growth, Inflation, and Current Account Balance.

	Real GDP growth (annual % change)			Inflation (% change in consumer prices)			Current account balance (% of GDP)		
	Actual	Projections		Actual	Projections		Actual	Projections	
Country	**2019**	**2020**	**2021**	**2019**	**2020**	**2021**	**2019**	**2020**	**2021**
Afghanistan	3.9	−5.0	4.0	2.3	5.4	4.8	11.7	9.5	7.8
Bangladesh	8.2	3.8	4.4	5.5	5.6	5.9	−1.7	−1.5	2.8
Bhutan	3.8	0.6	−0.5	2.6	3.6	4.6	−22.5	−21.4	−13.5
India	4.2	−10.3	8.8	4.8	4.9	3.7	−0.9	−0.3	−0.9
Maldives	5.7	−18.6	12.7	1.3	0.4	2.7	−26.0	−31.8	−17.0
Nepal	7.1	0	2.5	4.6	6.4	6	−7.7	−2.5	−7.0
Pakistan	1.9	−0.4	1.0	6.7	10.7	8.8	−4.9	−1.1	−2.5
Sri Lanka	2.3	−4.6	5.3	4.3	4.7	4.6	−-2.2	−3.6	−3.2

Sources: *Internal Monetary Fund, 2020.*

growth in the last few decades were fueled by their export growth. The USA, Europe and China are the main trading partners of the South Asian countries, and have themselves been affected badly by the pandemic with their economies slowing down. Because of the sharp drop in external demand, trade and exports contracted sharply as well. COVID-19 has thus heavily impacted both the export and import of South Asian countries. While exports have been growing steadily in recent decades, this year it is expected to be less than that of 2019 in all of the South Asian countries. Overall in South Asia, export growth will be from −6.8 to −3.9% and import growth from −7.3 to −6.2% due to reduced external demand, which will be low even beyond the lockdown period in 2021 (World Bank, 2020a). The reduced export earning is likely to compound the economic crisis in other sectors, like employment and household income. For instance, the textile and garments sector, which employs millions of people and contributes a lion's share of the export earning, is heavily dependent on external markets and will suffer heavily.

Inflation: The South Asian countries are expected to experience a slightly higher inflation in 2020 owing to the impact of COVID-19. Except Pakistan (10.7%), all other South Asian countries are expected to have a low level of inflation (0.40% in Maldives to 6.4% in Nepal) in 2020, which is comparable to 2019 inflation rates (**Table 1**). The current account balance (% of GDP) is expected to be negative for all South Asian countries in 2020, except Afghanistan. The deficit however is expected to be slightly lower than 2019 because of the sharp fall in oil price as well as due to the disruption in global supply chain, where imports are expected to be reduced more than the reduction in exports for most of the countries. South Asia region is a net oil importer and oil occupies the lion's share of the import bill.

Macroeconomic consequences. Lower revenue collection and higher recurrent spending are likely to increase the fiscal deficit to 7.7 percent of the GDP in 2020 (World Bank, 2020a). The high fiscal deficits in the region are adding to public debt, affecting fiscal sustainability. Low or negative GDP growth, declining export earnings and increased fiscal deficit have serious implication to household income and poverty. Over time, the macroeconomic crisis will translate to broader macroeconomic challenges that will lead to falling demand and mobility disruptions. The existing macroeconomic crisis may cascade to different economic sectors and compound the impacts at local economy and unfold many economic crizes through both forward and backward linkages and impact both supply (national, regional and global supply chains) and demand (consumption, saving and investment) as well as change prices. If the crisis prolongs, many SMEs may not survive and migrant workers will not be able to return to their original jobs; the recovery could take even longer and these economies may enter into the worst economic recession. The governments of the South Asian countries, therefore, face huge challenges in managing this unprecedented situation, which has major implication for the poor and marginalized communities. With temporary sealing of the border and restriction of the movements, informal cross-border trade is heavily affected, not only putting a number of informal enterprises involved in the supply chain of those goods at a higher risk, but also leading to shortage of groceries, particularly for landlocked countries like Bhutan and Nepal that are heavily dependent on import of basic goods from India.

Impact on Migration and Remittances

Due to restrictions in travel, mobility and gatherings, the most affected sectors are tourism, sports, entertainment (cinema), education, transport, manufacturing, migration and remittances. South Asian countries rely on foreign remittances as one of the main sources of foreign exchange earnings and household income. With closure of the remittance transfer businesses, loss of employment abroad, and absence of travel back home, remittance inflow in South Asia is expected to decline significantly.

Migration and the resulting remittance is one of the important sources of livelihoods for millions of poor households in the region (KNOMAD, 2020; World Bank, 2020c). The inward remittance from migrant workers serves as a lifeline for their families and as an important source of foreign currency, which contributes significantly to the national economy. For instance, in Nepal, remittance contributes about 27% of the national GDP (2019). India is the largest receiver of international remittance,

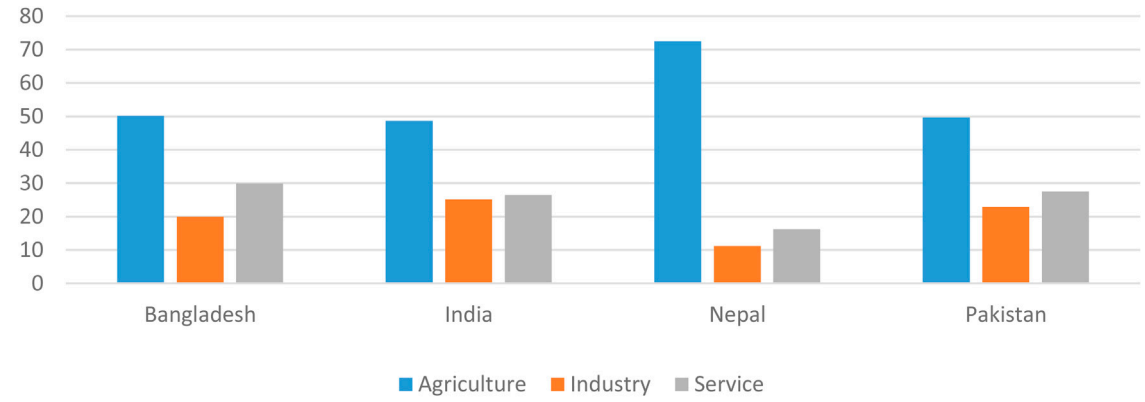

FIGURE 1 | Informal employment in South Asia in agriculture, industry and service sectors. Source: ILO, 2018.

not only in the region but globally, with US$ 83 billion in 2019. Remittance is also an important source of household income in other South Asian countries where the remittance-GDP ratio was 8.2% in Sri Lanka, 7.9% in Pakistan, 5.8% in Bangladesh and 4.6% in Afghanistan in 2019 (World Bank and KONOMAD, 2020). Like external migration, internal migration also contributes significantly to support families and ensure food and nutrition security for the poorer sections in the rural areas. The rural poor migrate to urban centers and support their families residing in rural areas. India has over 100 million internal migrants, who are also in huge numbers in other countries. The COVID-19 outbreak has placed many internal migrant workers in dire conditions, with many losing their (mostly informal) jobs and unable to return home due to disruptions in public transport services and movement restrictions. This is the reality for most migrant workers, especially those working in the informal sector and living in overcrowded slums. Lockdowns, travel bans, and social distancing measures in response to the COVID-19 crisis have disproportionately affected poor and vulnerable internal migrant workers, who have found themselves stranded, unable to return either to their places of work or their communities of origin. A number of newspaper articles reveal that thousands of workers marched to their villages from cities, despite movement restrictions and lockdowns. Without adequate access to housing, basic water and sanitation, health facilities, or social safety nets to help them survive in such restrictions, these migrant workers have become even more vulnerable to contagion risks. A recent survey in Bihar and UP in India reported that 73% of the respondent migrant households have lost their jobs or main income source (Population Council, India, 2020).

The migration and remittance sectors have been affected heavily by the COVID-19 pandemic. The initial estimates suggest that remittances will fall sharply in all of South Asian countries in 2020. The remittance flow will drop about 23% in comparison to 2019 in India, Pakistan, and Bangladesh. In Nepal is expected to fall by 14%. In total, in South Asia, remittance flow is likely to decline from US$ 140 billion in 2019 to US$ 135 billion in 2020 and projected to decline to US$ 120 billion in 2021 (World Bank and KNOMAD, 2020). The coronavirus related global economic slowdown, falling oil prices and travel restrictions may also affect the demand for migrant labor and migratory movements, and this is likely to keep remittances subdued even in 2021. These forecasts were done in the initial phase of the lockdown, but recent data suggest that the remittance inflow may not be affected as much when compared to 2019. However, many migrant workers from the region are infected with the virus in their work destinations with some causalities and with millions stranded in need of repatriation, which poses huge challenges and risks.

Losing Jobs in Informal Sector and MSMEs

In South Asia, a majority of the population is either self-employed or engaged in agricultural and related activities. Service and industry sectors are other major employers in the region, while micro, small and medium enterprises (MSMEs) and the informal sector services engage the largest workforce. (**Figure 1**).

For instance, in India 36 million MSMEs employed 60 million people and contributed significantly in national economy (Dev and Sengupta, 2020). In Nepal, MSMEs generates over two million jobs and contributes 22% of the country's GDP (Shrestha, 2020). In other South Asian countries, MSMEs also play a very important role in providing employment and income, contributing to exports and earning foreign currency.

The informal sector in general and MSMEs in particular have been hit hard by COVID-19 across the South Asia. The informal enterprises and wage labourers face daunting challenges. Many MSMEs are now closed as they could not sustain themselves through the lockdown, leaving many informal sector workers unemployed; economic losses accumulated due to reduced demand, restriction of movement, lack of access to markets, and the loss of mobility of people and goods have all affected workers (ILO, 2020a). COVID-19 restrictions have brought major economic activities to a standstill and have closed the operation of almost all MSMEs except a few health related enterprises. For example, in Nepal, more than a million informal sector workers have lost their jobs temporarily or permanently and are in need of relief materials from the state (Awasthi, 2020). Since hotels and restaurants have been closed for months, demand for food and related materials have also declined sharply.

TABLE 3 | Basic facilities in health sector and Social Security Coverage in South Asian countries.

Countries	Public health exp (% GDP)	Basic sanitation services	Employment with social security	Employment without social security	Potential job losses (millions)
Afghanistan	0.49	38.75	3.7	96.3	12.37
Bangladesh	0.47	43.78	2.5	97.5	
Bhutan	2.49	65.67	14.00	86.00	
India	0.91	50.48	10.3	89.7	112.8
Maldives	5.21	96.2			
Nepal	1.00	51.28	3.4	96.6	2.27
Pakistan	0.72	54.45	3.9	96.1	11.71
Sri Lanka	1.62	93.41	24.1	75.9	0.92
World	5.8	69.94	41.3	58.7	

Sources: ESCAP, 2020.

TABLE 4 | Health security ranking and score of South Asian countries.

Countries	Global health security rank and score*	
	Rank	Score
India	57	46.5
Bhutan	85	40.3
Pakistan	105	35.5
Nepal	111	35.1
Bangladesh	113	35.0
Sri Lanka	120	33.9
Maldives	121	33.8
Afghanistan	130	32.3

Source and notes: Higher the score better (lower) the rank. Score is 0–100. 100 is the best health security condition. The rank and scores are based on the following criteria: ***A)*** *Prevention of the emergence of release of pathogens;* ***B)*** *Early detection and reporting for epidemic of potential international concern;* ***C)*** *Rapid response to and mitigation of the spread of an epidemic;* ***D)*** *Sufficient and robust health system to treat the sick and protect health workers;* ***E)*** *Commitment to improving national capacity, financing and adherence to norms, and* ***F)*** *Overall risk environment and country vulnerability to biological threats. source: Babu et al (2020)*

In Pakistan, about 12 million workers were likely to face layoffs due to lockdown and the country's sluggish economic recovery (PIDE, 2020). It is also anticipated that if COVID-19 induced situation restricts the GDP growth rate between 0 and 1.5%, it is likely to increase the percentage of poor population (of income poverty) from 25% to around 55% (PIDE, 2020).

The high rate of layoffs and closure of a considerable portion of business will have multiplier effects on employment, household income, food and nutrition security and livelihood security. As most of the workers in the informal sector are poor and the majority of them are women, it has significant implications to poverty, gender and food and nutrition particularly for the marginalized communities who engage heavily on the sector for cash income and livelihood. Food insecurity is another major challenge caused by the disruption of agricultural production, food supply chains, and loss of income across different countries due to the pandemic. At the same time due to the low supply of agricultural production, food prices have been increased leading to severe impacts on household food security. The most vulnerable population in South Asia are those exposed to weather related disasters (flood, droughts), conflict or are living in extreme poverty in countries with weak social protection programs. The strain on incomes resulting from the decline in economic activity will devastate workers close to or below the poverty line and will bring additional people under poverty.

Inadequate Social Security Coverage

All South Asian countries have lower than world average public health expenditure (**Table 3**). As percent of the gross domestic product (GDP), the Maldives has the higher share of public health expenditure (5.2%) while Bangladesh has the lowest share (0.47% of GDP). A recent study shows that the some of the cities in South Asia (Karachi in Pakistan and Delhi in India) severely lack intensive care beds, healthcare workers and financial resources to meet the growing demand for healthcare services due to the coronavirus transmission (Davies et al., 2020). Other than Sri Lanka (24%), Bhutan (14%) and India (10%), social security coverage of the workers is quite low where less than 4% of the workers have some kind of social security. Around 140 million workers are expected to lose their jobs in the region (ILO, 2020b; UNESCAP, 2020).

The following table (**Table 4**) shows the average score of Global Health Security (GHS) index for South Asian countries. The global average of the GHS score is 40.2. Among the South Asian countries, India and Bhutan are above the global average while the remaining countries (Pakistan, Nepal, Bangladesh, Maldives and Afghanistan) are below the global average score.

Effect on Travel and Tourism

Some of the most affected sectors in South Asia due to COVID-19 are tourism, hotel and restaurant, manufacturing, construction and real state, agriculture, transport, trade and so forth (ESCAP, 2020). In the region, travel and tourism sector created around 50 million jobs in 2018 (**Table 3**), contributing significantly to the national GDPs. For instance in India, tourism and travel services employ about 43 million people contributing over 9% of the GDP; in Pakistan, it contributes over 7% of the GDP; and in Nepal, it employs over one million people contributing about 8% of the GDP (**Table 5**).

The COVID-19 mitigation measures including social distancing and travel restrictions have affected the travel and tourism sector the most. Demands in the tourism, travel, hotel

TABLE 5 | Employment and economic contribution of tourism and travel industry in South Asia.

Country	Share of GDP (%)	Number of jobs in T&T (in Thousand)	Share in total employment, most recent year (%)	Growth (2018 or latest year)
Bangladesh	4.4	2,414	3.9	11.6
India	9.2	42,673	8.1	6.7
Maldives	66.4	69	32.4	7.9
Nepal	7.9	1,051	6.7	3.6
Pakistan	7.1	3,850	6.3	7.4
Sir Lanka	12.5	1,000	12.1	12.4

Source: *World Bank (2020a).*

and restaurant sectors collapsed immediately after the spread of the coronavirus, which consequently affected the travel and tourism industry severely. For instance, on March 12, the Nepal government canceled all Everest expeditions slated for 2020 spring season. In the previous years, the Department of Tourism used to collect approximately US$ 4 million annually in royalties from Everest climbing permits. In addition to permits, each climbing team used to spend US$ 40,000–90,000 for other expenses (ICIMOD, 2020). The tourism sector, which generates huge revenue and provide employment to a considerable portion of people, has therefore been extremely affected (ICIMOD, 2020).

It is estimated that in the trekking sector alone, thousands of people will be severely affected while approximately 20,000 tour guides will lose their jobs (De Silva, 2020). The hospitality sector, which employs up to 60,000 workers in Kathmandu, Pokhara and Chitwan, has already been severely impacted by the drop in tourism (Shrestha, 2020). Similarly in India, 40–50 million job cuts are imminent from big hotels, travel agencies and tour operators (Dev and Sengupta, 2020). Bhutan incurred a loss of US$ 4.4 million and Bangladesh lost US$ 470 million from both domestic and international tourism (UNWTO, 2020). Because of the travel ban, the airlines industry is the hardest hit and unlikely to recover soon.

The COVID-19 pandemic is expected to affect the tourism demand and supply in South Asia differentially. At the demand side, international inbound tourists are expected to be reduced, while regional and domestic tourists to be increased. From the supply perspective, loss of jobs and closure of businesses run by MSMEs in the short term, are expected to recover and revive from the medium term onwards due to a growth in regional and domestic tourism in the region.

Impact on Agriculture and Rural Livelihoods

Due to the COVID-19 pandemic, agricultural value chains and livelihoods of the agriculture dependent population has been suffering (Morton 2020; Sulser and Dunston, 2020). In South Asia, majority of the rural population depend on agriculture and agri-related activities. Agriculture in this region is labor intensive and employs over 50% of the respective countries' labor force. Because of its high labor intensity, agriculture based rural economy and livelihoods are disrupted by COVID-19 and resultant quarantine, restrictions on movement of goods and services and closure of cross-border trade (Sulser and Dunston, 2020; Rasul, 2021). The COVID-19 induced disruption affects the agriculture and the entire food system – the production, transportation, marketing, distribution and consumption. Out of panic, even a few grain exporting countries in the early months of covid-19 restrictions have restricted their exports, which disrupted the international trade, eroded confidence on the global food market and cultivated insecurity (IFPRI, 2020).

COVID-19 has disrupted agricultural operation in the South Asian region because of shortages of labor and inputs, as shut-downs extended to rural areas, village roads, transportation and marketing of goods, all to control the movement of people in order to effectively curb the spread of the pandemic. The outbreak was initially experienced during the planting and harvesting season of many crops, including wheat and paddy, the two major staple foods in the region (Rasul, 2020).

Most affected sub-sectors are fruits, vegetables, poultry and dairy. For example, the poultry sector in Nepal has been losing Rs 220 million per day in recent months (Shrestha, 2020). Fruits are the major cash crops in the region, and the sector was affected badly due to transportation ban and lack of storage and processing facilities. Similarly, dairy farmers could not sell milk; beekeepers could not migrate their bees for spring blooms or get buckets for collection/storage of harvested honey and perform honeybee colony multiplication work/ queen rearing, and people could not collect/harvest non-timber forest products (NTFPs) either.

Shocks in Agriculture and Food Security due to the COVID-19

Although in developed countries the impact of COVID-19 on agriculture is relatively less, in South Asia the impact is substantial because of less mechanization and high labor intensity in agriculture. Across South Asia, rural populations depend on agriculture and agriculture-related activities for their livelihoods; about 50% of the workers are engaged in agriculture (Rasul, 2020 ; Rasul, 2021). While the current policy measures of social distancing and lockdown are critical to save people's lives and for combating the spread of the corona virus, these measures have affected the agricultural operations with many migrant workers unable to participate in agricultural activities. The disruptions arising from COVID-19 responses have impacted agricultural activities and its supply chain, including the marketing, transportation, distribution and consumption of agricultural goods and inputs in South Asia (Rasul, 2021).

The intensity of COVID-19 shocks on agriculture in the South Asian countries is high because the timing of the COVID-19 pandemic outbreak coincided with the planting and harvesting season of many crops including wheat, paddy, fruits and vegetables. For instance, in Bangladesh, farmers could not deliver harvested watermelon to markets due to transportation bans (Das et al., 2020; ICIMOD, 2020; van Bodegom, and Koopmanschap, 2020). According to FAO (2020), the pandemic restrictions in Bangladesh severely hampered the country's export of tropical fruits. Additionally, due to travel restrictions, seasonal labourers could not reach the agricultural sites for the Boro rice harvest, which accounts for over half the nation's rice production. Marketing and selling of poultry, dairy and fruits have also been affected severely in many South Asian countries, particularly the hill and mountain regions. Despite government many efforts, urban poor households in Bangladesh faced acute food insecurity during the lockdown period (Das et al., 2020).

COVID-19 has disrupted food transportation and supply chain in different parts of South Asia. Because of transport restriction and market disruptions, prices of farm products have collapsed and farmers have had to sell their harvested products at very low rates. For instance, farm prices for wheat in India have declined substantially due to lack of facilities to transport the harvest to the markets (Dev and Sengupta, 2020). Similarly, demand for poultry has also shrunken considerably. While prices of farm products have declined, the consumer price of many essential food items increased in almost all the South Asian countries during the initial outbreak of the COVID-19. During the lockdowns most of the countries experienced higher prices of food items and even shortage of food. The situation was further aggravated by the restriction of cross-border movement of goods and trade. A few of the major grain-exporting countries also restricted their exports out of fear of domestic food shortages, which disrupted international trade and regional food markets, and caused acute scarcity in import dependent countries. Border restrictions furthermore affected the transport of agricultural inputs such as chemical fertilizers, seeds, and farm equipment. A decline in food and inputs trade affected food availability in remote areas and may have caused price hike in food importing countries like Afghanistan, Bhutan, Maldives and Nepal (ICIMOD, 2020). For instance, in Afghanistan, initially food prices increased by 30% in Kabul when its border with Pakistan closed, with wheat flour prices increasing by 80–100% in March (Rahim, 2020). Meeting food and nutritional requirements in many South Asian households has been a challenge due to the increasing food prices and loss of jobs during the period of the lockdown. Many poor households have been pushed to cut their expenditure on food items which has compromised their nutrition. Several households have even been forced to borrow money or use their savings to buy food. As estimated by the United Nations University, the COVID-19 pandemic will push 16 million people in South Asia into extreme poverty (Sumner et al., 2020; UNESCAP, 2020). Moreover, a global economic slowdown is highly likely to force international migrant workers to return to their home countries, thus drying up vital foreign exchange resources in many South Asian countries which will consequently affect their food purchasing power.

Socio-Cultural Impacts

Physical isolation caused by the lockdowns has impacted social relationships, social interactions, and shed light on deep-rooted social norms and exclusions all over the world including South Asia. Sudden layoffs and loss of work have led to depression, alcoholism, substance abuse, and in some cases suicides (Hossain et al., 2020). Although poor and disadvantaged groups suffers more. Newspaper reports and videos circulating on social media record thousands of migrant workers stuck at national and international borders, unable to return to their own homes expressing a sense of abandonment, unfair treatment, and rage. The negative psychological impacts of the pandemic and measures to contain it are raising concerns about mental wellbeing, especially that of senior citizens, frontline healthcare providers, and individuals with existing health problems. The restricted mobility caused by lockdowns has been especially challenging for chronic patients and the differently abled who require regular medical care, but in many cases, have been unable to access it. There is very little public information available regarding the conditions of those living in state institutions—prisons, mental health institutions, shelter homes, and orphanages (ICIMOD, 2020). Many students whose campuses are closed find themselves stranded, often very far from their homes and many express a sense of hopelessness. Sudden layoffs and loss of work have led to depression, alcoholism, substance abuse, and in some cases, suicides. Closure of schools has also denied to children of poorer households, access to mid-day meals which could have adverse effects on nutrition, resulting in increased rates of stunting (UNESCAP, 2020). It is also reported domestic abuse of women has sharply increased during the lockdown period in many parts of South Asia (ICIMOD, 2020). The covid-19 pandemic has intensified the existing inequalities and further creating new forms of exclusion.

EMERGING SOCIAL RISKS AND VULNERABILITIES

Social protection system is very limited across the South Asian countries, where vulnerable population is expected to face unprecedented challenge due to the COVID-19 pandemic at their own expense. A huge share of populations in the region is involved in informal work with daily wage labor. The COVID-19 pandemic is likely to bring additional risks and challenges for South Asia, impacting communities and households through multiple channels. The poorest of the poor households and communities have already been impacted through the collapse/reduction of tourism, sharp fall in migration and remittances (both external and internal), and loss of jobs in the urban areas. Informal jobs in the cities and urban areas have evidently shrunk. Large numbers of internal migrant workers have returned back home and many international

TABLE 6 | Emerging social risks and challenges and possible socio-economic implications.

Drivers/triggers	Emerging risks and challenges for south Asian countries	Socio-economic implications
•Corona virus hits in waves and there is huge uncertainty about the future of the spread of the corona virus •Corona virus continues to spread and the economic slowdown continues •Extended lockdown	•Increased uncertainty about future of the spread of the corona virus •High risk of fiscal deficit and macroeconomic instability •Devastating economic impacts especially for mountain economies •Increased lockdown and devastating impacts on the regional economy	•Higher risks and vulnerabilities in mountain areas •Increased health risks and inaccessibility to health services •Overburdened health systems •Prolonged economic recovery and high economic and social costs
•Shrinking global demand, reduced exports, increased spending on COVID-19 risk management and social protection	•Increased risks on macroeconomic stability and investment for economic recovery •Increased fiscal deficit and monetary burden due to declining revenues and increased public expenditure	•Compounded economic challenges •Slow economic recovery •Increased pressure on already fragile livelihoods
•Declining informal employment when factories, construction sites, hospitality/service sector and other informal businesses are closed in the cities •Slow revival of MSMEs •Some SMEs do not survive the crisis •Reverse migration takes place in mountain areas	•Increased unemployment and underemployment •Dwindling MSMEs and informal businesses •Declining household income •Increased economic vulnerability •Losing development gain and increasing poverty	•Double burden for mountain economies and increased economic vulnerability •Losing jobs and income •Deteriorated mountain economies and livelihoods •Increased need for improving local economic opportunities to engage the returnee migrants in productive activities •Increased challenge for creating jobs in mountain areas including in public works
•Migrant workers cannot return to their original jobs in the country •Increased return of migrant workers from abroad due to limited job opportunities in destination countries	•Decreased domestic and international migration and remittance •Increased vulnerabilities of migrant households •Increased risk on food insecurity	•Protracted challenge of repatriation of returnee migrants and engaging them in productive economic activities •Increased need for ensuring cross-border migration in the region •Undermines economic stability and affects livelihoods •Falling into poverty trap
•Slow revival of tourism due to high avoidance and risk behavior •Extended length of avoidance behavior	•Reduced income from travel and tourism •Affected jobs and livelihoods	•Increased challenge of reviving tourism sector •Bhutan, Nepal and other mountain areas may face protracted challenges due to high dependence on international tourists •Increased risks and vulnerabilities on mountain livelihoods •Loss of livelihoods, indebtedness, loss of productive assets •Increased risk of slipping into poverty
•Reduced household income •Decline in people's purchasing power •Breaks in food supply chains •Increased uncertainty of agricultural and rural operations •Increased restriction on export of food and other important agricultural products	•Increased risks of hunger and food insecurity •Adverse impact on food production and supply chain and on food prices •Reinforced inequality	•Increased indebtedness, loss of productive assets •High vulnerabilities and food insecurity •Heightened need for maintaining buffer food stocks •Increased need for regional cooperation to smooth movement of food •Increased need for international cooperation to ensure continued flow of food •Long-term adverse impact on future generation
•Households losing an important source of livelihood and income with high risk of chronic poverty •Limited fund availability for poverty alleviation programs •Increased cost of living	•Increased poverty and inequalities •Increased strain on social safety nets	•Exacerbated existing poverty and vulnerabilities •Leading to deeper poverty and inequality trap •Increased poverty and heightened vulnerabilities •Exacerbated existing inequalities
•Disruption of agricultural production and transportation of foods	•Increasing food panic buying	•Undermine mountain food security

(Continued on following page)

TABLE 6 | (*Continued*) Emerging social risks and challenges and possible socio-economic implications.

Drivers/triggers	Emerging risks and challenges for south Asian countries	Socio-economic implications
•Soaring unemployment, low income, food insecurity and increasing level of anxiety among people may generate discontent and frustration fueling violence and conflict	•Increased social tension, disturbances and crimes •Increased gender and social conflict	•Exacerbated existing inequalities and social tension and conflicts •Chronic poverty sliding back in the hills and mountains •Deeper poverty and inequality traps •Reinforced inequality •Increased social tension, disturbances and crimes

migrants are also returning or will have to return to their respective countries of nationality in the short- or medium-term. These initial impacts of COVID-19 will, however, permeate to other sectors including agriculture.

Besides the loss of income from job and migration, the South Asian population will suffer from the dampened demand of their products and services due to fall in aggregate demand and avoidance behavior (e.g., tourism, travel, recreation) due to ongoing risks of contracting the virus. Moreover, the loss of income and fall in remittances may increase indebtedness and force households to sell their productive assets and/or severely restrict the ability of the poor households to invest in education of their children, and/or compromise on their nutrition, which will have long-lasting effects. This may deepen poverty, inequalities and vulnerabilities in the region. The economic and social costs of the COVID-19 outbreak are likely to be significant and long-lasting.

Besides few online schooling, most of the schools are closed and millions of children are out of school. It is expected that many children, especially girls, marginalized communities, and the disabled may not be back to school, as they will be forced to make up for their household income loss caused by the pandemic. **Table 6** presents the existing drivers, emerging risks and challenges, and potential implications for South Asia.

It is evident from **Table 4** that the Covid-19 pandemic has led to multiple risks and challenges. Due to the restriction on travel, tourism, and gathering of people to maintain physical distancing, the demand for all kinds of goods and services are suppressed due to forward and backward linkages. As a result, trade volumes (both imports and exports) have declined considerably. However, the domestic spending on health sector, and social security has been increased, but tax revenue declined which have macroeconomic implications.

As a large share of economic activities in South Asia are informal, the closure of factories and restaurants, and the decline of tourism and demand for goods and services, has shrunk the region's labor absorption capacity. As a result, unemployment rates have soared while incomes have declined (CMIE, 2020). This has made millions of households vulnerable to poverty.

When factories, construction sites, travel and tourism sectors closed, migrant workers returned back to their villages. This return-migration trend is also taking place at the international level, where migrant workers working in foreign countries have lost their jobs and are returning back home. Returnee migrants need additional support for their survival and in the absence of such support system, their families are more likely to be vulnerable to poverty since households not only need to support additional members but have also lost remittances. Covid-19 is likely to deepen poverty and reinforce inequality, increase social tension, disturbances and crimes in South Asia.

EMERGING OPPORTUNITIES

The current situation provides a unique opportunity to use the disruptive forces of the COVID-19 pandemic and the associated policies for recovery; to accelerate the transition to more sustainable and resilient societies (Rasul, 2020). Some of the short-term measures to address the challenges of COVID-19 can be linked to economic growth by investing in natural capital to improve the long-term productivity and resilience in the region. This requires strategic thinking and strategies for long-term investment to ensure that short-term actions result in long-term benefits. Short-term support can be linked to long-term socio-economic growth through appropriate planning and strategizing which will improve the social and environmental conditions for the sustainable recovery of the health and economic sectors (Rasul, 2020). For example, food for work programs can be linked to programs that construct or maintain local infrastructure such as roads, irrigation canals, management of watershed thus helping poor households to cope with vulnerability while building assets that are essential for society. Similarly, requirements to include energy efficiency in building designs can be linked to support provided to building construction companies to restore jobs, thus providing job restoration in the short-term and climate benefits in the long-term.

Leveraging Civil Society and Private Innovation

The lockdown has also prompted actors involved in supply chains to adapt a number of important private sector innovations to cope with the pandemic restrictions (Sulser and Dunston, 2020). E-commerce has been growing steadily in the recent years in South Asia due to increased digital connectedness and the development of information and communications technologies. During this period, for instance, consumer-led groups on Twitter, Facebook, and WhatsApp have organized with Farmer Producer Organizations in several countries to find ways of bringing

food to markets (Narayanan and Saha, 2020). Many farmers began delivering produce directly using WhatsApp to secure aggregated orders in housing cooperatives in nearby cities (Narayanan, 2020). In India, Swiggy, a fast-growing food delivery app and logistics company, delivers for 40,000 restaurant partners, helping them with its "jumpstart package" to recover sales, while the Swiggy Capital Assist Program helps pay for hygiene and distancing upgrades. During the farmers' markets shut down, some farmers traveled to cities to set up shop at roadsides maintaining physical distance. In India, Flipkart is growing fast during the COVID-19 crisis and developed a "hyperlocal delivery"grocery service linking SME suppliers with domestic supermarket chains like Vishal Mega Mart with its e-commerce operations (The Economic Times, 2020). Nepal's nascent e-commerce sector has also growing steadily since the lockdown started.

Global energy demand has declined sharply due to the mitigation measures of COVID-19 and energy price is also going down sharply. Since most of the South Asian countries are net energy importers, the falling oil price could benefit these countries. The reduced oil prices will not only lower the import bill but also help save foreign exchange and will have positive impacts on the current account balance. For example, India is the fourth largest consumer of oil in the global market and a rough estimate suggests that "a US$ 10 fall in crude could reduce the current account deficit by approximately 0.5% of GDP and the fiscal deficit by around 0.1% of GDP" (Sandeep Nayak, The Economic Times, January 12, 2015). The lower oil prices will have positive impacts on manufacturing, cost of fertilizer production for agriculture, costs of transportation and many other energy dependent sectors. The Pakistan government has already declared a reduction in oil prices by Rs. 20 per liter (DAWN, 2020). The decrease in oil prices will decrease production cost and can have positive impacts on managing inflation and living expenses.

Another sector with future growth potential is health services and medical goods and services. Because of COVID-19 pandemic, people are now more conscious about health and the governments may thus invest more in strengthening health facilities. This is likely to increase the demand for health and medical products, including food items with health benefits. This could create an increased demand for health and medicinal products, including the foods with nutritional benefits. The pandemic and resultant disruption in supply chain has created a need for proper development of local economy, local food system, and both on- and off-farm activities. Other important areas of emerging opportunities could be the development of internet-based service sectors. The pandemic has created additional demand for internet-based economic activities, such as online shopping, distance education, as well as online medical services and work from home, which may change the demand for office space and travel needs. Policies that reduce job market frictions and facilitate labor adaptation to these job opportunities would be needed, once the pandemic is controlled in working toward a self-reliant economy for the region.

The COVID 19 pandemic also provides an opportunity to build resilience in the most vulnerable region through the use of stimulus packages to tackle the poverty and other issues. The government may plan strategically to prevent risks and improve resiliency, for instance by promoting sustainable development to reduce the impact of other shocks, such as natural disasters, in the future. As South Asian countries have committed to meet the SDGs by 2030, the governments should utilize their resources and invest in assisting the people affected by the COVID-19.

GOVERNMENT AND CIVIL SOCIETY RESPONSES

The governments of South Asian countries have responded promptly and adopted several policy measures to contain the spread of the COVID-19, support the poor people to ensure food, and provide stimulus to economic sectors. In this section, we briefly present the economic response measures taken by South Asian countries.

Response to Support Vulnerable People

The major focus of government response on preparations to contain the spread of the virus, increase resources for the health-care system including financial support for medical testing and treatment of the disease, as well as fiscal support for emergency public interventions to increase hospital capacity and medical supplies. All the governments have strengthened their social protection programmes (cash and asset transfer, including food) and provided resources for supporting poor and vulnerable groups, and provided wage support to low-wage workers. For instance, the Government of Afghanistan allocated US$ 15 million to contain corona virus; the Government of Bangladesh allocated US$ 29 million to fund the COVID-19 preparedness and response; the Government of India allocated US$ 22.6 billion to provide essential food items, health facilities, fuel and direct cash to support the poor people and senior citizens; and the Government of Pakistan introduced a relief package worth US$ 7 billion for next three months. The governments of Bhutan, and Nepal also adopted different social protection measures to support poor and vulnerable groups. For example, Nepal government took full responsibility of bearing the cost of testing and treatments of people who have been infected by the coronavirus. In some of these countries, monetary incentives and support was also provided to encourage people to comply with the quarantine efforts. Besides government support, NGOs, civil societies, private sector and religious organizations also extended their support in providing food and essential items to the poor. In Pakistan, government has Ehsaas program to strengthen coordination with NGOs and other civil bodies to target the poor population for delivery of rations more effectively.

Response to Minimize the Short-Term Economic Pain

Besides supporting vulnerable people, governments of South Asian countries have also adopted various fiscal and monetary measures to minimize the short-term economic pain and to inject liquidity into the financial system. The governments have adopted different measures including concessional lending to

prioritized sectors, reduced restrictions on payments such as forbearance of taxes, rent and utility payments and deadlines for loan payments to make liquidity available and to provide flexibility for debtors. For instance, the Reserve Bank of India rolled out a plan of 1.8% of GDP to increase liquidity in the financial sectors. In addition to the central government efforts, some States in India also adopted stimulus measures to sustain economic activities and support the poor. For instance Kerala State has announced US$ 2.6 billion package (2.5% of the state GDP) for economic recovery and some direct transfers to poor households (World Bank, 2020a). Similarly, Government of Pakistan introduced a huge stimulus package and financial support including US$ 600 million support to SMEs and tax refunds to the export industry (World Bank, 2020a). Government of Bangladesh announced the plan of US$ 588 million salary support to garment and other export industries to support their workers. Government of Nepal also introduced concessional loans for SMEs to pay their workers.

Response to Reopen and Revitalize Economy

Different countries adopted different strategies for gradual opening of the economies and providing financial support to priority sectors to revive economic activities. Government of India has adopted a measure of zoning the country based on the prevalence of the coronavirus cases to relax the lockdown and gradually restart economic activities in areas where the virus is absent or low in number, yet taking stringent measures in the hotspot areas. The state government of Assam, India has constituted a task force to design strategies to revive the state's economy. India's central bank has introduced measures to increase liquidity to increase access to credit for the pharmaceutical, construction and tourism industries. Bangladesh government is providing 50–70% subsidy to farmers for buying harvesters to address the challenges of labor shortage in paddy harvesting. The governments of Bhutan, Myanmar and Nepal have also rolled out different measures to stimulate SMEs (World Bank, 2020a). It is heartening that Benapole- Petrapole land border between Bangladesh and India has opened recently after three weeks of lockdown to facilitate movement of people on emergency ground (ICIMOD, 2020).

CONCLUSION AND POLICY RECOMMENDATIONS

The COVID-19 pandemic has posed a huge risk and severely impacted the socio-economic condition and livelihood of people in South Asia. The coronavirus is still spreading and it is difficult to predict when it will be completely contained. The unprecedented challenge posed by the COVID-19 pandemic calls for very urgent and decisive actions to ensure that people's lives are saved, livelihoods are protected and the economy recovers. The Covid-19 outbreak has caused direct high costs on human health and economic activities, and poses the most adverse effects on livelihoods of the poor and the most vulnerable communities. This study discusses some of the crucial key points that may help assist vulnerable group of people who are suffering from this pandemic. Since the coverage of social security system is minimal or absent altogether in most of the South Asian countries, the government should manage to give some sort of social security facilities to the poorest population, more specifically when they lose their informal employment opportunities. Improving saving habits of the poor and providing access to banking services would, for instance, provide safety nets during times of crisis.

As health, environment and social issues are interconnected, concerted efforts are required to mitigate and recover from the damages brought by the COVID-19 on our societies and economies. Governments need to prioritize their activities for short, medium, and long-term. Regional and global cooperation is also necessary to address the ripple effects of COVID-19 on different societies. The countries of South Asia must act collectively to address their challenges and to create favourable conditions for economic recovery. Importantly, innovative strategies and approaches are needed to address the coronavirus challenges. The governments of the South Asian countries may consider the following policy measures to mitigate the negative impacts of the pandemic on the poor and most vulnerable sections of the society and to promote economic recovery.

- **Plan for an economic recovery from COVID-19** to develop a strategy to adapt quickly based on the situation, avoiding blanket lockdowns so that areas with low intensity risk are not affected due to closure of the local economies, since blanket shutdown of the economy has taken a devastating toll on the economy and people's livelihoods. The Indian approach of categorization of the country based on the prevalence of the corona virus cases and opening the economic activities in areas where virus is absent or low, and introducing stringent measures in hotspot areas could be a good starting point. Detailed guideline, however, is necessary to operationalize such policies, such as following clear protocol developed based on local condition and evidence as well as clear strategies for containing the virus after opening. Due to the lack of such protocols, the risk of resurgence of the COVID-19 virus is quite high in these countries, as it is has evidently been occurring in the United States and European countries. It is important to use the media intensively to raise awareness among public and disseminate targeted health care education and self-protection as well as supporting mental health (Khajanchi et al., 2020).
- **Develop roadmap for achieving short, medium, and long-term goals** to revitalize the national and sub-national economy by taking into account the specific condition and needs of the poor and vulnerable groups at sub-national level. In the short term, focus should be on addressing the immediate health crisis, ensuring food and nutritional security, shorter-term job creation and transferring incomes to the needy population to survive the economy. Medium term focus should be on boosting economic activities to recover the economy and in designing and implementing the best possible stimulus to achieve financial recovery. The long-term

goal should be **t**ransforming or bouncing the economy forward by promoting long-term sustainable growth and poverty reduction.

- O**rchestrate the fiscal, monetary and development interventio**n in an integrated and coordinated manners so that different policy measures complement each other and multiply their effects in economic recovery. While the short-term focus will be on addressing the impacts of the pandemic and restoring jobs and employment, the long-term focus could be on improving long-term productivity and resilience by investing in a balanced portfolio of physical, human, social and natural capitals, which will build capacity to deal with future challenges and mitigate the impact of future pandemics and other socio-economic shocks. For example, investment in health, education, skills development, innovation, technological upgrading, and green infrastructure and natural capital will increase the productive capacity of the population and provide sustainable returns for future generations.
- **Redouble the efforts of social protection** to protect the poor, vulnerable groups, and migrant workers and compensate the loss of income so that they can maintain minimum standard of living and do not slide back to poverty. Investment in social protection and job creation will be needed to protect the vulnerable in the short term, but policy priorities could gradually shift to reducing the environmental risks affecting human health and vulnerability to climate change. Protecting and enhancing natural capital such as forests, soils, water resources, ecosystems, biodiversity, air quality, and climate can support human health and productivity and improve long-term resilience. For example, investment in green infrastructure such as renewable energy can supply clean energy and improve air quality, which leads to long-term health benefits and positive climate outcomes
- ***Boosting economic** activity and i*nvesting in job creation in areas where poor and lowly skilled workers can participate and get benefits. In striving for sustainability, policy choices, and investment decisions should be arranged strategically in such a way that they not only address immediate problems but also build long-term resilience, **strengthen the existing poverty alleviation program** and targeted poverty reduction programs in asset building and economic recovery.
- **Promote regional cooperation** to facilitate expedient cross-border movement of essential goods and services including medicines, medical equipment, foods, and other essential items. South Asian countries must work together to address the challenge of pandemic and fast and sustainable economic recovery.
- **Review and revise the policy priorities** by withdrawing subsidies from fossil fuels and providing subsidies to green recovery, improving health facilities, boosting economic activities, and focusing on programs that alleviate poverty and vulnerabilities. The drop in oil prices offers an opportunity to withdraw the existing subsidies on oil and other fossil fuels and invest more on renewable energy sectors that support green jobs. Local food system should also be strengthened at community levels to improve local food self-sufficiency and nutritional outcomes.

DATA AVAILABILITY STATEMENT

The original contributions presented in the study are included in the article/Supplementary Material, further inquiries can be directed to the corresponding author.

AUTHOR CONTRIBUTIONS

GR, conceptualization, writing and rewriting; AN, AH, AM, SR, AL, PG, FA, AM, ES provided inputs.

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Data on an Austrian Company's Productivity in the Pre-Covid-19 Era, During the Lockdown and After Its Easing: To Work Remotely or Not?

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The Covid-19 crisis across the world has increased the proportion of e-working. The transition from cubicles to the home office raised many questions in connection with companies adopting the new working conditions. Our paper provides recent evidence on the extent of this move, its impact on workplace evolution, productivity and the future prevalence of the face-to-display workplace after the easing of the lockdown. It uses data from 154 service employees of an Austrian sports and leisure product company obtained using online surveys on employees' opinions on e-working. By a coincidence, we conducted the first of them shortly prior to the epidemic. We decided to modify our planned research goals and decided to study their opinions during different Covid-19 stages. As a result, our findings do not follow all the academic standards. First, they are almost impossible to replicate due to the specific coincidence. Then, the shift in our aims leads us to minor changes in the content of the questionnaire. There are not only significant differences in the proportion of workers in the office and at home during the different periods of the lockdown. After its end, there was a significant increase in the number of those who had started working at home—more than one half. Compared to the period prior to the lockdown, they have a tolerant attitude to their work from home and believe that their productivity might remain the same. For many of them the change was an unavoidable obligation so they would prefer to return to the traditional workplace. The results suggest that more than one fifth want to continue working from home permanently, about one third more frequently than before, more than a quarter sometimes and just one seventh not at all. We studied the issues related to their productivity and its limits during all three stages. There are three important reasons for the fall in productivity related to e-working: (1) Providing childcare/home schooling, pet sitting and/or care for others while working (>one-fourth); (2) Work-from-home routine (>one-fourth); and (3) Having less work to do (>one-fifth).

Keywords: face-to-display workplace, productivity, fall in productivity, COVID-19, future prevalance

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INTRODUCTION

Covid-19 had spread worldwide by the first weeks of 2020 and was declared a pandemic in March 2020 (WHO, 2020). Reducing face-to-face contacts is an important action to mitigate its impact (ILO, 2020). According to Baldwin and Weder di Mauro (2020), the Covid-19 economic crisis has been an unprecedented shock for the European economy and society, and it requires swift policy action and a coordinated fiscal response. Many governments enforced regional lockdowns. The Austrian government responded by requesting people to refrain from leaving their homes and by encouraging e-working wherever possible (OTS, 2020). Companies were forced to increase their remote work. With a figure of 9.9%, Austria had a high percentage of telework among the countries of the European Union in 2019 (Eurostat, 2020a). Despite widespread promotion by the government and organizations in recent years, the utilization rate of telework has remained stable (Eurostat, 2020a). The European figures are rather low. Blinder (2009) estimated the upper limit of jobs in the US that could potentially be done offshore in 2004 at between 22 and 29%. In 2013, all measures found that roughly 25% of US jobs can be done offshore (Blinder and Krueger, 2009). In a recent study, the authors' classification shows that 37% of US jobs can plausibly be performed at home (Dingel and Neiman, 2020).

The epidemic launched an e-working experiment across the world. Prior to it, the home office was only used by a few individuals or small groups in 75% of Austrian companies. The situation has changed suddenly. A total of 90% of those surveyed stated that at least half of the workforce worked from home during the lockdown (Deloitte, 2020). In nearly 60% of companies, almost all employees worked from home. Among the companies that took part in the survey, 96% used home offices intensively during the lockdown (Deloitte, 2020). Across the European Union, over a third (33.7%) reported working exclusively from home during the pandemic (Eurofound, 2020). Furthermore, Brynjolfsson et al. (2020) found that about half of US employees are now working from home, including 35.2% who reported they were previously commuting, but recently switched to working from home. Their survey estimates that the share of remote workers in the US has quadrupled to nearly 50% of the nation's workforce. In the past, e-working was a privilege for a select few. In this crisis, however, it has become a necessity and an established way of working. The factors that drive e-working are long commuting times, the rise of gig-economy employment opportunities, work-life-balance demands and the spread of Covid-19.

Telecommuting, virtual office, and telework are a few of the terms used to describe the same phenomenon (Siha and Monroe, 2006) with different dimensions, e.g., duration, schedule, location, task, synchrony, voluntariness, ICT, contract (Allen et al., 2015; Nicklin et al., 2016) and Covid-19. E-working is a method of working by making use of information and communications technology (ICT) in a situation in which the work is not bound to any particular location. Traditionally this has been understood as working away from the office, usually at home, either full-time or for part of the working week (WDC, 2017). In our study, e-working (face-to-display workplace) is where employees work at home full-time/part-time, on a hybrid basis or at a different place or virtually. In brief e-workers are those workers who, in the time of Covid-19, are working outside the organization's premises using modern technology.

Disagreement over the performance of remote employees has received widespread attention in recent years. Some argue that working from home allows employees to be more productive due to fewer office distractions, while others disagreed and maintained that the home is not the best environment because it is subject to home distractions (Fonner and Roloff, 2010). Bloom et al. (2015) found that call-center workers at a large Chinese travel agency randomly assigned to work from home 4 days a week for 9 months increased their performance by 13% compared with those who stayed in the office. Work-from-anywhere arrangements could be even better for productivity than working from home, depending on the type of work (Choudhury et al., 2019). However, Battiston et al. (2017) revealed in a natural experiment that the physical proximity of workers in the same office improves productivity through better face-to-face communications. Dutcher (2012) found, on the basis of a laboratory experiment, that a telecommuting environment may have positive effects on productivity for creative tasks but negative effects on productivity for dull tasks. Generally, e-working makes employees happy, and satisfied employees are usually more productive.

The widespread demand for e-working, the significant policy drivers and the increase of its utilization during Covid-19 have emphasized the need for real-life evidence. Our research was conducted by means of online surveys. It addressed the following research questions:

- RQ1: Is there a difference of proportion between cubicle workers and transited e-workers (i.e., those who were not working online prior to the pandemic)?
- RQ2: What impact has e-working had on the productivity of face-to-display workers?
- RQ3: What may cause falling productivity at home?
- RQ4: The pandemic has accelerated the implementation of e-working—will it last?

It is important to say they the fourth question was added during the research. Our initial aim was to study just the first three only. As the pandemic critically affected all participants and they had to move to their home offices, we were interested whether this experience would affect their future and how.

The following section provides an account of the concept of workplace productivity. The third briefly outlines the methodology used in this research. The fourth section gives an overview of our results. Then follows a section presenting our discussion, and the last section gives the conclusions.

THEORETICAL BACKGROUND

Workplace flexibility, the digitisation of work, the increased blurring of boundaries between work and private life, modern ICT, the global economy and the Covid-19 crisis, all these

developments will continue to affect every part of our social and economic life. The investigation of these factors started years before the pandemic.

Evans et al. (2004, p. 2) define flexibility in the employment relationship as "ceding control to workers over the circumstances of their work by enabling them to vary those circumstances to address personal and family needs and uncertainties." Flexibility generally covers temporal flexibility (flexitime, nine-day fortnights), spatial flexibility (how the physical work space is designed and used) and geographic flexibility (where the work is done). E-working is one of a number of possible work practices of this kind. Currently, it is the most preferred, effective and complete among them as it incorporates many elements of temporal, spatial and geographic flexibility.

Taylor (1911) argued that the best way to boost productivity was to embrace three rules: break complex jobs down into simple ones, measure everything that workers do and link pay to performance, giving bonuses to high-achievers and sacking sluggards. Digital Taylorism seems to be a more powerful tool than its analog predecessor (Schumpeter, 2015) because every move of e-workers can be easily controlled by dedicated software. With the demands on the modern workplace generally rising, Moore (n.d.) highlights "businesses are faced with a wealth of new external and internal drivers to force managers to provide a workplace that supports business objectives while providing employees with an environment where they want to work and that will allow them to be at their most productive." From this point of view, e-work is also a way of diminishing the stress that is often prevalent in today's workplace. Stress and excessively long working hours contribute to the deaths of ∼2.8 million workers every year (ILO, 2019). This is also confirmed by a study by Sayah and Süß (2013), which illustrates that the work-life conflict of contract workers is significantly influenced by working hours and income. Research shows that changes in working conditions can provoke conflict between work and private life (Byron, 2005). The extractive approach, which treats people and planet merely as resources waiting to be exploited for profit, does not represent the current situation.

Productivity is commonly defined as a ratio between the output volume and the volume of inputs (OECD, 2020). The productivity of workers could thus be measured as an output, e.g., sales or units produced, relative to an input, e.g., the number of hours worked or the cost of labor. Traditionally, labor productivity is derived from aggregate measures at the firm level, e.g., value added per worker (Sauermann, 2016). Further, Pritchard (1992, p. 455) defines productivity as follows: "... how well a system uses its resources to achieve its goals." With this definition, productivity is a combination of both efficiency and effectiveness. Productivity as a term is closely related to both performance and effectiveness (Jayamaha and Mula, 2011). While performance and effectiveness relate to the employees' ability to perform in accordance with what is expected of them and measures their output in terms of quality, productivity takes the cost of achieving performance or effectiveness into account (Jex and Britt, 2014). While productivity increase is a benefit for the individual employee, because it improves efficiency (for example, it removes distractions and reduces time spent commuting), it has also shown evidence of increasing the productivity of output, i.e., performance, and thus generating a beneficial productivity increase for the organization; Nilles believes that telework on average increases the productivity of employees by 5–20% (Nilles, 1997).

Generally, productivity depends on several factors that affect the employee's productivity levels. Todays' e-workers have a wide range of choices on how, when and where their work will be done. Several studies have investigated the impact of e-working on productivity (Dutcher, 2012; Laihonen et al., 2012; Bloom et al., 2015; Gambardella et al., 2015; Battiston et al., 2017; Beno, 2018; Iazzolino and Laise, 2018; Palvalin, 2019). Generally, team productivity is different from individual productivity. Some studies analyzed the relationship between working from home and employees' productivity. The results revealed a positive effect on employees' productivity (Bailyn, 1988; Olson, 1989; Dubrin, 1991; Hill et al., 1998; Bélanger, 1999). Further research investigated the influence of working from home on employees' productivity; data from laboratory or field experiments were used in order to estimate the positive causal effect of working from home on employees' productivity (Dutcher, 2012; Bloom et al., 2015). Peters et al. (2004) find that organizations rank productivity and work quality problems second among the drawbacks of working from home. Monteiro et al. (2019) suggest that remote work has a significant negative effect on labor productivity, though the productivity loss is relatively modest in magnitude (around 2.3%).

DATA AND METHODOLOGY

Data Collection

The current e-working framework in our examined company (an Austrian sports and leisure product company) was implemented 10 years go with its policies and practices, and the setting up and monitoring of results. E-working enabled the organization to drive down their cost base and increase the engagement of their people. To be eligible, employees had to put their request for e-working to their manager. The number of these approvals was 34 out of total 250 employees.

The preparation of our research started prior to the epidemic. As a large proportion of the workers had had some experience of home-office working, our initial aim (RQ1) was to investigate whether there was a difference of proportion between cubicle workers and transited e-workers (i.e., those who were worked online occasionally). We wanted to learn whether there is any impact from e-working on the productivity (RQ2) as well as what may cause falling productivity at home (RQ3).

The questionnaire was pre-tested by a selected group of 12 employees.

After its revision, our first questionnaire was emailed to all employees and completed by 154 (response rate 61.6%). To get a realistic picture, we wanted to cover at least 20% of their current working week. For that reason, all 34 employees who were already working were invited to participate.

Email notifications were sent to all employees in order to inform them of the questionnaire, its purpose, dates, etc. A total

of 154 employees participated in the survey (including the 12 pre-testers). For the study of work/e-work productivity, the following criteria were used in our final selection:

- All were workers in the service sector;
- All had some experience with e-working;
- Due to the presumed long-term study, all agreed to participate in all the rounds of the survey (the current and next ones).

The group consisted of 34 e-workers (20 male and 14 female) and 120 cubicle workers (68 male and 52 female). The sample was a heterogeneous group of professionals working in several areas, including customer services, accounting, electronic data processing, research and development, marketing and logistics.

Our research was carried out using a quantitative approach. The first survey was run on 28 February 2020—before the extent of the pandemic was recognized. Responses to the questionnaires were anonymous. The questions of the survey covered an agreed set of topics (such as job satisfaction, technology, working patterns, etc.) and demographic information. Characteristics of the survey respondents, such as gender, age, marital status, parity, and official homeworking status were included under the presumption of their relevance to their personal position toward e-working (see **Table 1**).

The groups are similar in all parameters except one—their age. The distribution indicates a higher age among e-workers than among cubicle workers. The age difference is presumably caused by the necessity to mentor less experienced employees; the more experienced ones are given more freedom. This explanation fits well with the traditional view of management, and with our original aim, which was designed and developed to provide a better understanding of workplace changes and employee productivity in on-line and on-site working conditions. For this reason, we opted for cubicle workers and e-workers who had some experience of e-work prior to our research (see **Table 2**). The reason for this requirement was so that respondents were capable of responding to and discussing the issues of e-work productivity.

Suddenly, the situation changed. Due to the pandemic, all participants had to respect restrictions. As a result, additional questions addressing RQ4 were added to reflect the spread of Covid-19. This extended version was then run during the lockdown (31 March 2020) and after it was eased (29 May 2020). **Table 2** shows a sudden jump in the February and March figures. The size of the increase demonstrates the effect of the lockdown. The difference between February and May is more interesting. The number of e-workers more than doubled. Further research will have to be done after the epidemic is over in order to determine the future impact on the face-to-display workplace in the company.

Tables 3, **4** relate to productivity and deal with possible cases of a fall in productivity among e-workers. The scale of responses comparing productivity at the end of March and at the end of May were as follows: I get much more done, I get a little more done, I get the same done, I get a little less done, and I get much less done. In the final stage of the survey, respondents were also given the choice of a number of possible reasons for the fall in productivity.

In the May survey, we included another question about the future prevalence of the face-to-display workplace after the easing of the lockdown (see **Table 5**). The last added question (RQ4) was: After the easing of the lockdown, how often would you like to work from home? The response choices were: never, sometimes, often and always.

There is a reliability risk with e-mail questionnaires because it is more difficult to guarantee anonymity, and respondents may have concerns that the information they provide may be misused. To assure them that this would not happen, the authors of the paper proceeded in the following manner. First, the anonymity of their responses was emphasized in the questionnaire invitation. There was also a description of the procedure that was then followed. We used trusted software that did not allow linking identifiers with their responses. Their personal information and responses were stored in separate files. And then the authors made certain that all IP addresses, e-mail data and other personal data were not archived.

Data Analysis

In the first stage, we used cross-tabulation of data to examine relationships within the data. In the second stage of our analysis,

TABLE 1 | Socio-demographic characteristics.

	Cubicles		E-working	
	N	**%**	***N***	**%**
	120	77.92%	34	22.08%
Sex				
Male	68	44.16%	20	12.99%
Female	52	33.76%	14	9.09%
Age				
20–29	25	16.23%	3	1.95%
30–44	58	37.66%	12	7.79%
45–59	37	24.03%	19	12.34%
Marital status				
Single (divorced, separated)	67	43.51%	22	14.29%
Married/partnership	53	34.41%	12	7.79%
Parity				
Children in household	99	64.29%	26	16.88%
Childless	21	13.64%	8	5.19%

TABLE 2 | Profiling main place of work during three periods.

	Prior COVID-19		Lockdown		Easing restrictions	
Place of work	***N***	**%**	***N***	**%**	***N***	**%**
Cubicle-centered workers	120	77.92%	12	7.79%	66	42.86%
E-workers	34	22.08%	142	92.21%	88	57.14%

TABLE 3 | E-working productivity.

Profiling main place of work during lockdown	E-workers (34)	%	Transited e-workers (108)	%
I get much more done	14	41.18	11	10.19
I get a little more done	12	35.29	9	8.33
I get the same done	2	5.88	57	52.78
I get a little less done	3	8.82	19	17.59
I get much less done	3	8.82	12	11.11
Profiling main place of work after easing lockdown	**E-workers (34)**	**%**	**Transited e-workers (54)**	**%**
I get much more done	14	41.18	20	37.04
I get a little more done	12	35.29	13	24.07
I get the same done	2	5.88	9	16.67
I get a little less done	3	8.82	8	14.81
I get much less done	3	8.82	4	7.41

TABLE 4 | Main reason given for fall in productivity ($N = 88$).

Main reason given for fall in productivity	*N*	%
Providing childcare/home schooling, pet sitting and/or care for others while working	25	28.41
Work-from-home routine	23	26.13
Having less work to do	19	21.59
Lack of motivation/focus/concentration		
Limited access to workplace resources and interaction with others, and changes to work organization because of Covid-19	12	13.64
Sharing space and equipment	6	6.82
Equipment, software, and/or internet connection	3	3.41

we used the McNemar test to determine the consistency in the responses across two variables. We tested two workplace moves to determine whether there is a significant difference between the proportion of workers working from home and those working from cubicles in all three examined periods. In the next step, we examined productivity. We used Pearson's chi-square test to determine whether there is a difference between the productivity of e-workers during and after the lockdown.

TABLE 5 | Working at home preferences after social distancing.

Working at home preferences after social distancing (%)	N	%
Never	23	14.94
Sometimes	43	27.92
Often	54	35.06
Always	34	22.08

FINDINGS

The following paragraphs provide an overview of the findings from the quantitative component of the research study. Austria traditionally has low levels of unemployment and high social standards. Increased ICT has given rise to new forms of employment in Austria and throughout Europe (Eu2018at, 2018). According to Eurostat data (Eurostat, 2020b), the Netherlands topped the list of EU member states for the number of people working from home, closely followed by Finland (13.3%), Luxembourg (11.0%), and Austria (10.0%). The lockdown restrictions imposed by the Austrian government led to a rapid growth of e-working.

In our investigated company, work carried out in cubicles (77.92%) exceeded the rate for e-workers (22.08%) before the lockdown. During the lockdown, the proportion changed dramatically in favor of e-workers (cubicles—7.79% to e-workers—92.21%), and after the easing of the lockdown the proportion became more balanced (cubicles—42.86% to e-workers—57.14%). See **Table 3**. This was possible due to excellent technological connectivity, which according to Messenger and Gschwind (2016) facilitates the process, since it allows work to be done anywhere and at any time. Data collected before the lockdown show that e-working was more prevalent among male employees, whereas during and after the lockdown it became a necessity for everybody. This confirms Beno's (2019) survey data that telework is a male-dominated working method. Nearly 4 in 10 people in the EU began working from home as a result of the Covid-19 pandemic (Eurofound, 2020).

To answer the first research question (RQ1), we examined the outcome data statistically with the assistance of the McNemar test. In this first question, we used pre-, during and post-lockdown data to find out whether employees worked at home or not. All *p*-values (marked in yellow, see **Tables 6**–**8**) of the McNemar test are below the significance level of 0.05. According to the data, there were considerable differences in the proportion of workers in the office and at home during all three periods. Over the course of the surveyed periods, the e-working proportion increased on average by 57.14%. Briefly, this surge in e-working occurred during the lockdown (92.21%).

Employers expected about 44% of workers to start working from home during the pandemic; 78% of business leaders think hybrid and home-working will have a negative impact on productivity (WEF, 2020). In the midst of the Covid-19 crisis, e-working became a lifesaver for all employees who could do this kind of work. Then a question appeared: Would the

TABLE 6 | Workplace * Period Cross-tabulation and Chi Square tests.

			Period		Total
			Profiling main place of work February	Profiling main place of work during lockdown	
Workplace	Determined cubicle-workers	Number	120	12	132
		% within period	77.9%	7.8%	42.9%
	Determined e-workers	Number	34	142	176
		% within period	22.1%	92.2%	57.1%
Total		Number	154	154	308
		% within period	100.0%	100.0%	100.0%
Chi-Square Tests					
	Value	**Exact sig. (2-sided)**			
McNemar test		**0.002[a]**			
N of valid cases	308				

[a] *Binomial distribution used.*

TABLE 7 | Workplace * Period Cross-tabulation and Chi Square tests.

Workplace * Period Cross-tabulation

			Period		Total
			Profiling main place of work February	Profiling main place of work after easing lockdown	
Workplace	Determined cubicle-workers	Number	120	66	186
		% within period	77.9%	42.9%	60.4%
	Determined e-workers	Number	34	88	122
		% within period	22.1%	57.1%	39.6%
Total		Number	154	154	308
		% within period	100.0%	100.0%	100.0%
Chi-square tests					
McNemar test		**0.002[a]**			
N of valid cases	308				

[a] *Binomial distribution used.*

sudden and dramatic increase of e-working make the workers more productive or not? Bloom et al. (2015) found that a company's staff became notably more productive by working from home 4 days a week. Recent results from a Canadian survey suggest that one third of respondents said they feel that their productivity has increased since they started working remotely—this despite the fact that more than half the participants in the study are working with another person at home (Udemnouvelles, 2020).

Our evidence, using Pearson's chi-square, suggests that after the lockdown there was a significant increase in the number of transited home-centered workers (those who had just started working at home) who had done a little more or much more than during the lockdown. The biggest difference is for workers with long experience who claim that their labor productivity did not change in any period. During the lockdown this applied to more than half of the workers, whereas after the lockdown it was only a third of the workers who continued working at home (after previously working in an office) as shown in **Table 9**. Apparently, those who do not feel comfortable with e-work tend to be less productive.

The *P*-value (1.64396) is lower than the chosen level of knowledge; we reject the null hypothesis of independence. The periods before and after the lockdown show a significant impact on labor productivity. These periods also differ markedly in three categories: I get a little more done, I get much more done and I get the same done.

What causes productivity to fall at home? There are three important reasons for the fall in productivity related to e-working: (1) Providing childcare/home schooling, pet sitting and/or care for others while working (28.41%); (2) Absence of work-from-home routine (26.13%); and (3) Having less work to do (21.59%). There is no magic formula. What employees should do to maintain a good balance of productivity and happiness while working from home depends on their own personality and probably on their individual time management.

The last research question related to the future prevalence of the face-to-display workplace after the easing of the lockdown.

TABLE 8 | Workplace * Period Cross-tabulation and Chi Square tests.

Workplace * Period Cross-tabulation					
			Period		**Total**
			Profiling main place of work after easing lockdown	**Profiling main place of work during lockdown**	
Workplace	Determined cubicle-workers	Number	66	12	78
		% within period	42.9%	7.8%	25.3%
	Determined e-workers	Number	88	142	230
		% within period	57.1%	92.2%	74.7%
Total		Number	154	154	308
		% within period	100.0%	100.0%	100.0%
Chi-square tests					
	Value	**Exact sig. (2-sided)**			
McNemar test		**0.000[a]**			
N of valid cases	308				

[a] *Binomial distribution used.*

TABLE 9 | Cross-tabulation for e-workers productivity.

Productivity	**During lockdown**		**After easing of lockdown**	
	Absolute frequency	**Relative frequency**	**Absolute frequency**	**Relative frequency**
I get a little less done	19	17.59%	8	14.81%
I get a little more done	9	8.33%	13	24.07%
I get much less done	12	11.11%	4	7.41%
I get much more done	11	10.19%	20	37.04%
I get the same done	57	52.78%	9	16.67%
Total	108	100.00%	54	100.00%

The May 2020 survey asked respondents how often employees would like to work from home after the end of social distancing. The results suggest that more than one fifth (22.08%) want to continue working from home always, more than one third (35.06%) often, more than a quarter (27.92%) sometimes and just over one seventh (14.94%) not at all.

DISCUSSION

The pandemic has changed our working opportunities and habits. It affects all five generations included in the production processes: traditionalists (born prior to 1946), baby boomers (born between 1946 and 1964), Gen X (born between 1965 and 1976), Millennials, also called Gen Y (born between 1977 and 1997) and iGeneration born after 1997. They all have to find their new workplaces on the Internet.

This allows us to define Workplace 5.0 as a multigenerational workplace continuity in management and supervisory practice which are important for success in supporting multiple generations (Yang and Guy, 2006). Clearly, there would be similarities as well as differences between them. The term "period war of talent" was coined in 1997 and refers to the changing landscape at the workplace to attract and retain talent. Since then, the situation is becoming more challenging. Nowadays, it is very hard to fix the borders since it also depends on personal mindsets. For those who come through the current crisis reasonably well, the economic aspect will be the most important. More than ever, the reduction of costs will be the main focus and will play a central role in the context of Workplace 5.0. Covid-19 brought a completely new, previously unseen aspect: social distancing (including the tightening of hygiene restrictions). E-working and the home office are not just a solution to a crisis, they will be essential components of the future style of work.

This implies that the focus on the post-Covid-19 workplace will be determined by the following formula:

$$C \times S \times E = \text{Workplace 5.0}$$

where:

C stands for cost reduction;

S stands for the necessity to maintain a social distance; and

E stands for e- and hybrid working, i.e., the possibility to work regardless one's location.

At the same time, there are no adequate tools to measure employee productivity, task completion and timeliness (Joice, 2000). That is why our research has concentrated on the employee's personal feelings about his/her productivity. As a minimum, such subjective evaluation can express to what degree the person's productivity differs from its "standard." Any deviation will affect the productivity of the company as a whole.

However, it has been said that measuring productivity is not as important as measuring the quality of its outcome. Managers need to develop a way to measure both (Joice, 2000). The ability to evaluate an employee's productivity is important, because it relates to the possibility of promotion, compensation and more (Baffour and Betsey, 2000). Again, individual evaluations do not solve the problem, but can serve as a benchmark for decisions

whether to make a transfer to home office, with whom and to what degree.

How do employers measure the productivity of e-workers and co-located workers in an e-economy? The basic formula for productivity, namely output divided by input, measures production (output) over a set period of time (input). Can we implement a similar formula for e-working? What is it that is being produced in e-working? Is input (time) important? In unskilled work, the task obviously is, but in e-working this is rarely the case. We cannot remove the human aspect from work and productivity. A satisfied employee produces work of high quality, and vice versa. We are of the opinion that a mixture of quantitative and qualitative measures is needed. Wasted work time must also be taken into account, which includes absenteeism and presenteeism (being at work, but not being productive). In a productive organization, everyone shares the same approach to what is crucial, but not urgent, vs. urgent but not crucial. This applies not only to the employee, the team or the division, but to the organization as a whole.

Can employers measure the productivity of e-workers and co-located workers in an e-economy? According to Choudhury (2019), companies that let their workers decide where and when to do their jobs—whether in another city or in the middle of the night—see increased employee productivity, reduced turnover and lower organizational costs. A universal metric for measuring the true productivity of e-workers has not been devised yet. Employers have found innovative ways to measure and improve productivity. In our opinion, the effective measuring and improving of productivity in a company depends on the sector, but its key components must be achieved outputs and individual satisfaction (internal or external), i.e., measuring objectives instead of working hours.

E-working is currently the only safe work form in the face of Covid-19. Will this e-working experiment lead to greater expansion of this mode of working in the future, or will it remain a privilege for the few, as it was before Covid-19?

CONCLUSION

The main research questions investigated in this paper are:

- RQ1: *Is there a difference of proportion between cubicle workers and transited e-workers (i.e., those who were not working online prior to the pandemic?*) The number of employees working remotely has increased in all three periods, according to our results. The e-working proportion increased on average by 57.14% between February and May, i.e., between two periods when the employees were not obliged to do e-working.
- RQ2: *What impact has e-working had on the productivity of face-to-display workers?* Based on our data, productivity has increased on average. On the other hand, those who do not feel comfortable with e-work, tend to be less productive.
- RQ3: *What may cause falling productivity at home?* (1) Providing childcare/home schooling, pet sitting and/or care for others while working (28.41%); (2) Absence of work-from-home routine (26.13%); and (3) Having less work to do (21.59%).
- RQ4: *The pandemic has accelerated the implementation of e-working—will it last?* E-working and the home office are not just a solution to a crisis, they will be essential components of the future way of working. The concept of Workplace 5.0 is the key to this.

Before Covid-19, European countries were reluctant to implement e-working. Telework increased slowly in the 10 years before the outbreak of Covid-19, mostly as an occasional work pattern (EC, 2020). In the two decades before Covid-19, remote work increased steadily, but comprised a relatively modest share of the labor force (Ozimek, 2020). All in all, the post-Covid survey results suggest that over half the workforce is now remote (Brynjolfsson et al., 2020). Our results show e-working increasing, having a significant effect on productivity and undergoing increased implementation in the future. Initially, we conclude that e-working is here to stay. According to a BBC Survey, 50 of the biggest UK employers have no plans for all their staff to return to the office full-time in the near future. Furthermore, 24 firms did not have any plans for workers to return to the office (Jack, 2020). We have come to the conclusion that the shift to working from home is and will remain a possible way to adapt to the Covid-19 demands on the workplace for the future. Data presented in our paper show the great extent to which e-working was adopted during the periods investigated.

According to our data, there are significant differences in the proportion of workers in the office and at home in all three periods. After the lockdown, there was a marked increase in the number of workers (that is those who started working at home) who will do a small amount or a great deal more than during the lockdown. The biggest difference was for workers who claim that their labor productivity was the same in both periods. During the lockdown, more than half of those who previously worked in an office remained at home to work, after the lockdown only a third of them did. There are three important reasons for the fall in productivity related to e-working: (1) Providing childcare/home schooling, pet sitting and/or care for others while working (28.41%); (2) Work-from-home routine (26.13%); and (3) Having less work to do (21.59%). The results suggest that more than one fifth (22.08%) want to continue working from home always, more than one third (35.06%) often, more than a quarter (27.92%) sometimes and just over one seventh (14.94%) not at all.

Covid-19 has caused uncertainty and sorrow across the globe, but it also launched an e-working experiment. The shift to increased remote work could eliminate many of the challenges brought about by the consequences of Covid-19. But history has shown that society, organizations and managers need to anticipate workforce problems as people return to work. Covid-19 has not only economic, but also psychological and social implications. Although managers are key in the recovery process, they are also subject to human uncertainty. Information flow, scenario planning and risk improvement are extremely important during uncertain times. Managers are in a unique position to recognize e-working challenges that will put them in a better position than ever before to provide calm leadership and helpful guidance. Herein, lies the problem in the remote

vs. in-office debate. The question is not where we are more productive, it is rather about which space (office, home or virtual) provides more focus. We believe the question to be considered is what employees desire, namely how to provide an engaging experience without sacrificing concentration and productivity (which implies that Digital Taylorism should be diminished as much as possible in order to make home offices safe and protected places).

FURTHER RESEARCH

Further research should be carried out with data from the second series of lockdowns. This is needed in order to understand how additional data can throw further light on e-working as a dominant method of working. These investigations are important due to the prolonged isolation of employees which can affect their social comfort and result in them changing their previous attitude. Upcoming research should involve a more thorough investigation of how to measure e-workers' productivity. This can be done both through qualitatively focusing on case studies and through quantitative effect studies.

STUDY LIMITATIONS

The study in its present format is a result of coincidence. When it started, no one could predict the appearance of the Covid-19 pandemic. Due to our quick reaction, we could carry out the research described above, but it cannot be replicated in this format (unless one had a crystal ball). Nevertheless, some other factors also restrict the full generalization of our outcomes. Firstly, data collection took place by means of e-mail questionnaires because of distance, financial aspects and Covid-19. There is no guarantee that the researchers obtained all the possible information from the participants that could be used in the analysis of the data and results. However, the quality of the data depends upon the quality of the questions asked. Secondly, the sample does not reflect the population by sectoral structure. Lastly, the researchers have no way of ascertaining whether the respondents replied honestly or not. It should be stated that the results of this study do not necessarily reflect how the way that workers get to work will evolve in the post-pandemic period.

DATA AVAILABILITY STATEMENT

The original contributions presented in the study are included in the article/supplementary material, further inquiries can be directed to the corresponding author/s.

AUTHOR CONTRIBUTIONS

MB conceived of the presented idea, was engaged in the investigation, literature search and selection, verified the analytical methods, writing original draft, preparation, and finishing the last version. JH was involved in proof reading, forming conclusions, and limitations as well as in contribution to the last version. Both authors discussed the results and contributed to the final manuscript.

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Conflict of Interest: The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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Covid-19 Response From Global Makers: The Careables Cases of Global Design and Local Production

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Makerspaces—informal shared spaces that offer access to technologies, resources and a community of peer learners for making—across the globe initiated a rapid response to the lack of medical hardware supplies during the global pandemic outbreak in early 2020 caused by the Corona virus (COVID-19). As our health systems faced unexperienced pressure, being close to collapsing in some countries, and global supply chains failing to react immediately, makers started to prototype, locally produce and globally share designs of Open Source healthcare products, such as face shields and other medical supplies. Local collaboration with hospitals and healthcare professionals were established. These bottom-up initiatives from maker networks across the globe are showing us how responsible innovation is happening outside the constraints of profit-driven large industries. In this qualitative study we present five cases from a global network of makers that contributed to the production of personal protective equipment (PPE) and healthcare-related products. We draw our cases from the experiences made in *Careables*, a mixed community of people and organizations committed to the co-design and making of open, personalized healthcare for everyone. With the presented cases we reflect on the potential implications for post-pandemic local production of healthcare products and analyze them from a social innovation perspective. These global experiences are valuable indications of transformative innovations that can reduce dependencies from international supply chains and mainstream mass production.

Keywords: COVID-19, makerspace, social innovation, open source hardware, DIY healthcare

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INTRODUCTION

"Makerspaces are informal shared spaces located in communal, educational and increasingly also commercial settings, which provide their members with access to technologies, resources and most importantly a community of peer learners for making" (Ahmadi et al., 2019).

During the rapid spread of the novel Coronavirus (COVID-19) worldwide, which puts our health systems under unexperienced pressure and brings them close to collapsing in some countries, we are all witnesses to the importance of the maker community for a rapid response to the lack of medical hardware supplies (Ranney et al., 2020). Across the world we see initiatives popping up where makerspaces are called to use their digital fabrication tools to, e.g., 3D print valves for life-saving Coronavirus treatments or face shields to offer some protective gear for doctors (Diez and Baeck,

2020). But not only does the maker community contribute to the rapid production of needed pieces, it also shows its responsible innovation capacities by rapidly prototyping, testing, documenting, and reproducing new products that are needed in times of this pandemic, such as hands-free 3D-printed door openers to help against the spread of Coronavirus. Medical Hackathons are organized around the globe to design and deploy Open Source Hardware (OSH) medical products.

However, this first aid response of the maker community does not go without friction, especially when dealing with critical medical equipment that needs to adhere to strict quality control and standards and represents a large business field for companies specialized in this area. One of the first instances of such a conflict appearing in international media was the case of a volunteer maker in Italy, who produced 3D-printed valves for life-saving Coronavirus treatments. The original manufacturing company refused to release the design files for the valves, forcing the volunteer maker to reverse-engineer the valve (Peters, 2020). The ethical question that remains to be answered in this case is whether the original manufacturer did not release the original files due to a concern of quality or due to a business-driven motivation. The great concern for quality standards is shared across the maker community and the rapidly established working groups and testing spaces with doctors. Makers are working with medical review teams to validate the utility and safety of new solutions quickly, before entering them into Open Source Hardware collaboration and hosting platforms (Brown, 2020).

The bottom-up initiatives from maker networks across the globe are currently showing us how responsible innovation is happening outside the constraints of profit-driven large industries. We are witnessing critical, socially responsible making these days and a professionalization of the maker-driven open hardware movement that is comparable to Open Source Software which is running the world nowadays. But is the maker community putting social interests before business interests? What effects will the Open Source hardware designs, that are currently being created and shared, have on the future of manufacturing? Will we see new collaborations across established industries and makers emerging? How will this affect society and especially the younger generation? These are just some of the emerging questions that science and technology studies in a joint effort of different disciplines still have to address.

In this paper, we build on the experiences made during the COVID-19 pandemic by a small number of globally distributed makerspaces and fablabs. We aim to provide rich descriptions of the makers' COVID-19 response and reflect on their potential wider societal implications in the future. The main objective of this study is to critically reflect from within the maker community on the crisis response actions taken, showing current challenges and limitations as well as offering a stimulus for further analysis of the transformative character of makerspaces. We have chosen a case study approach as in qualitative research the complexity of each case provides us with an important context for understanding the issue we are studying (Flick, 2017).

The five selected cases have previously been active in open healthcare practices and have been loosely connected via *Careables*, a project dedicated to personalized open healthcare (www.careables.org). While these maker communities all vary in their COVID-19 response approaches, which we discuss in detailed case description, a focus group discussion revealed a series of commonalities amongst makers when it comes to scaling their activities, which we then related to the theories of social and transformative innovation theories.

DO-IT-YOURSELF (DIY) HEALTHCARE, MAKERS AND HEALTH AND CARE PRODUCTS

Overview

Bottom-up digital social innovations are on the rise, including in healthcare. Over recent years we have witnessed a growing number of grassroots solutions in do-it-yourself (DIY) healthcare, including the development of Open Source hardware and DIY practices which may counteract current healthcare supply shortages. Via Open Source approaches communities can collaboratively improve and co-produce new solutions, in consultation with public health authorities (Richterich, 2020). Innovators, users of healthcare products, and communities in healthcare are starting to collaborate by using digital technologies to co-create knowledge and solutions for a wide range of needs. These solutions range from Open Source hand prosthetics, 3D printed writing tools to support kids with physical limitations, to add-ons for wheelchairs, and everything in between. If we look into the medical field, we see similar tendencies towards experimentation and creation of alternative solutions beyond the standardized practices, e.g., in the fields of biohacking, patient experimentation, and Open Source hardware for medical devices.

These community-led or civic innovations are responses to societal issues that cannot be met by our healthcare systems nor by industry. Criado, Rodriguez-Giralt and Mencaroni (2016) even position open design and participatory prototyping strategies in a more political context and stress the activist character when applied by the independent living movement in Spain. They relate the experiences of open prototyping with and by disabled people to the critical making notion defined by Ratto (2011), which stressed the learning aspects and the societal relevance of DIY activities in maker communities.

Closely related to these critical making properties is *Careables*, an initiative that is rooted in the context of personalized open healthcare development. It is a mixed community of people and organizations committed to the co-design and making of open, personalized healthcare for everyone driven by a set of underlying principles for responsible making. It started 2018 as a European funded innovation action under the Horizon 2020 program and has since grown to a worldwide community, mostly via a global network of social and technological innovators called Global Innovation Gathering (GIG). The *Careables* platform[1] and its documentation repository on Welder-app[2] currently registers

[1]https://www.careables.org/discover-careables/
[2]https://www.welder.app/careables

over 180 open designs for open healthcare solutions, next to other resources, such as legal and ethical guidelines or training resources. *Careables* encourages care receivers, healthcare professionals, and makers to join forces and to co-create tailor-made solutions designed for supporting and better suiting the care receivers' needs.

Further, the global network of fablabs recently launched Fab Care as a global initiative to support fablabs, makerspaces and hackerspaces which are working in assistive technologies, in creating personalized solutions for people with physical challenges to improve their quality of life.

Beyond the civic-innovation character, we also see more and more established healthcare institutions, such as hospitals, therapeutic and care centers, starting to work with digital fabrication tools. In some hospitals, makerspaces are already part of their infrastructure (Marshall and McGrew, 2017). While these initiatives are less driven by activism or socially driven innovation needs, they equally recognize the values of local on-demand production of spare parts in healthcare equipment, therapeutic devices, creativity, and innovative prototyping. In these health makerspaces medical staff find access to tools, materials, and the required knowledge to test new ideas and build prototypes. With the experiences of the momentary personal protective equipment (PPE) and other medical device shortage during the COVID-19 crisis on the one hand and digital fabrication tools and skills on the rise on the other, we may experience a growing penetration of a demand for local production in healthcare.

These developments obviously bring legal and ethical issues to the table such as do-it-yourself solutions that may not always comply with medical standards and regulations. Problems may range, for example, from intellectual property law (e.g., see the above-mentioned case of the 3-D printed valve) to safety and specific laws for medical devices and PPE. Part of these problems arises, as in most cases product laws are aimed at large organizations rather than small entities. Makerspaces and these new forms of collaboration blur the classic hierarchical dichotomy between producers and consumers (Daly, 2016; Kamenjasevic and Biasin, 2018) and result in greater problems in ensuring the legal compliance of the co-designed and co-created products.

Maker's COVID-19 Response Initiatives

In early 2020, when the COVID-19 pandemic had completely turned into the globally dominating health concern, bringing the health systems in many countries to their absolute limits, the reaction of the maker movement was instantaneous. Maker communities around the globe have been very active during the first wave of the COVID-19 crisis by responding to the shortage of PPE and other medical and healthcare-related products. One of the larger civic response communities is the Open Source Medical Supplies (OSMS)[3]. Initiated by Gui Cavalcanti, the founder and CEO of a robotics company, OSMS launched in March 2020 as a Facebook group, and rapidly brought together a global network of over 70,000 makers, fabricators, community organizers, and medical professionals in 55 countries collaborating on the unprecedented medical supply challenges caused by the COVID-19 pandemic. In their global impact dashboard, the network currently indicates that over 16 Million supplies have been delivered by the global community, with face shields being by far the most frequently produced device.

The variety of PPE and medical supplies that have been produced in these collective networks are said to include around 50 different products, ranging from door openers, and ear savers to intubation boxes. These PPE serve as a means to reduce the spread of the virus following the available evidence that the virus is transmitted via air droplets when in close contact with infected persons and not air-borne. Therefore by providing equipment that supports frequent and effective handwashing or acts as disinfectants, helps preventing contact with droplets or helps avoiding contact with contaminated surfaces like door handles, an effective preventive measure is being taken especially in healthcare and community settings. The knowledge and research done by the OSMS global network have been documented and shared in case studies, community stories, a project library that gives access to many open designs, a map to find local response groups, and the Open Source Medical Supply Guide (Open Source Medical Supplies, 2020). Also, the *Careables* community shifted its focus of activities from supporting DIY healthcare for people with disabilities to collecting, documenting and sharing information and Open Source solutions to fight COVID-19. The *Careables* COVID-19 collection currently includes around 50 Open Source hardware projects, ranging from different versions of face masks and shields to intubation boxes and door openers. In addition, background information and legal guidance on the responsible production and use of DIY products are shared with the maker community worldwide.

According to a survey done by the Fabfoundation (Fabfoundation, 2020), which was answered by 42 fablabs around the world, more than half of the 43 products made by the responding fablabs as a reaction to the COVID-19 crisis were locally approved or medically reviewed by an agency or organization. These include hospitals (for 22 products), healthcare professionals (for 15 products) or national (for 6 products) and local (for 2 products) healthcare institutions. The same report stresses the local context where most of the work happened to serve small local organizations in need. The authors of the study conclude that "A locally sourced, globally distributed manufacturing process could continue to fill an immensely important role in the months (and years) to come" (Fabfoundation, 2020, p.13).

Not only has the failure of global manufacturing supply chains accelerated the makers' response; another important factor triggering the community action has been the financially underserved and fragile healthcare systems in many countries. In the United Kingdom an analysis of the maker response to COVID-19 pandemic by Richterich (2020) clearly establishes a link between the national austerity politics and the strained healthcare system. When relating the makers' DIY production

[3]https://opensourcemedicalsupplies.org/

of healthcare equipment to the critical making theory of Ratto (2011) there is also a political dimension coming into play, as volunteers in makerspaces reacted to a governmental failure in healthcare supplies (Richterich, 2020).

Overall, the maker COVID-19 response initiatives strongly relied on the sharing of open designs and a self-organized production and dispatchment of the DIY equipment, via online and social media (Corsini et al., 2020; Zastrow, 2020). When a certain material was not locally available alternatives were explored, either by modifying the design, adapting material that was already available or hacking different parts of the product design (Fabfoundation, 2020). Richterich (2020) stresses this synergy of Open Source product design, it's re-use, it's adjustment, and it's local production as an open hardware product as a core characteristic of the maker communities' COVID-19 response.

SOCIAL AND TRANSFORMATIVE INNOVATION THEORY AND SOCIETAL IMPLICATIONS OF DIY OPEN HEALTHCARE

The volunteer-driven, self-organized activities of the maker community have significantly contributed to the response phase of the COVID-19 pandemic and also drew attention to the latent innovation potential of the general public (Corsini et al., 2020). Since the rapid emerging of local makerspaces, hackerspaces, fablabs and the calling out of a global maker movement (Dougherty, 2012) experts have assigned this new culture of local manufacturing certain social transformation power (Diez, 2012; Smith, 2017; Millard et al., 2018; Bosse et al., 2019; Unterfrauner et al., 2020). The technological innovations advancing the manufacturing capacities of digital fabrication tools have offered a wide range of possibilities for social and community action. As Ruiz Freire et al. (2019) exemplify with the three-dimensional additive printers, that are nowadays accessible on the home market, technological innovations can lead to strong social, environmental, economic, and political implications. Based on a bibliographic analysis of innovation processes, the authors argue to regard social and technological innovations not as separate phenomena, but rather to consider innovations in their social, technical, economic, educational, and political realm (Ruiz Freire et al., 2019). The examples of DIY open healthcare production that we have discussed above need to be analyzed in a multilayered perspective as well.

Smith (2017), who studies makerspaces as sites for democratizing innovation activity, assigns them social innovation potential. He describes them as *socially transformative, educationally useful and entrepreneurially promising*. They offer capabilities for participation, deliberation and community development, which constitute their transformational and democratic potential. At the same time makerspaces also reproduce dominant values of society and the global economy, e.g., when they follow an open innovation agenda that tries to leverage the makers' creativity for global manufacturing and following prevailing economic growth business models. Thus, we are witnessing contradictory developments of makerspaces, where we have open spaces aiming for democratic transformations next to spaces that adhere to traditional market-driven models (Unterfrauner et al., 2020).

From a critical making perspective, this path of entering the business-as-usual chain is not the one to follow, and many makers striking a social transformative or democratic path have started a search for more participatory models of production generally, and for the healthcare sector specifically. DIY manufacturing processes based on Open Source design may be social innovations that respond to certain social needs, but they also require new collaborative and financial models. Ratto (2011) critical making values, such as the societal relevance of making and the potential for learning and gaining critical knowledge during this process of material work, indicate the social and transformative innovation potential of DIY open healthcare production in maker communities.

As explained by social innovation theory, social innovations tackle social needs and respond to societal challenges (Holtgrewe and Millard, 2018). According to Bureau of European Policy Advisers (BEPA) (2010) societal levels model of social innovation, there are three interconnected levels, namely the social needs (micro level), the societal challenges (meso level), and the systemic change (macro level) (see **Figure 1**). At the micro level, social innovations are responding to local social demands, tackling specific problems on the ground that are not met by the market or public institutions. They respond in a bottom-up approach to the needs of particular groups, often including the beneficiaries themselves, such as vulnerable people. At the meso level, we see social innovations that are tackling societal challenges at large social scale or across whole sectors by combining social, economic, environmental, and cultural factors. It usually requires new forms of relations between actors, including adequate organizations, networks, and modes of collaboration for producing real and desired outcomes. At the macro level, social innovations generate system change. This can only happen when fundamental transformations in society are taking place, including a reform of underlying structures, changes in the relationships and powers in society. It often goes along with organizational and institution change, reforms of public policies, new governance arrangements and a changing mindset and cultures, allowing for more participation and empowerment. While this distinction of social innovations at the three levels is helpful for analysis it is also simplistic in a way, implying a somewhat linear view of society and possibly ignoring complex and unintended consequences (Holtgrewe and Millard, 2018). For the purpose of this work, it proves to be a useful instrument for discussing results of the makers' experiences.

The DIY open healthcare activities of projects such as *Careables* are located at the social demand level, tackling specific problems of people, often from vulnerable groups, that are not addressed appropriately by the market or institutions. The COVID-19 PPE production started at a micro level, but with the enormous impact that the epidemic has on our social, political

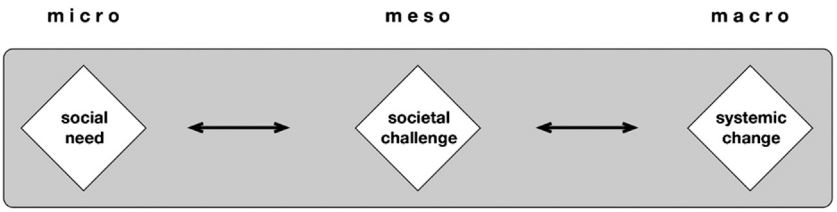

FIGURE 1 | Adaption of the three Bureau of European Policy Advisers (BEPA) (2010) levels of social innovation.

and economic systems, it also gets attention as a more societal challenge on a meso level. The third level, the systemic change or transformation level, requires fundamental changes in institutions, governance and policies. While in this analysis we will mostly stay at the micro level with the described cases, we want to explore how the actions and networks around the COVID-19 response of the maker movement may influence at meso and macro level, contributing to transformations in healthcare in the future.

METHODOLOGY

As the overall methodology, a qualitative case study approach was chosen since it represents a versatile form of qualitative inquiry that is suitable for a comprehensive and in-depth investigation of complex issues and unclear boundaries (Harrison et al., 2017). Representatives of makerspaces from the *Careables* project and the GIG (Global Innovation Gathering) network volunteered to participate in this case study. They are listed as co-authors and are referred to in the following text as "case representatives," sharing their insights and experiences through an interactive dialogue, guided by a self-reflection exercise and an online focus group discussion.

Involved Case Representatives and Researchers

For the purpose of this study five makerspaces that have been very active during the COVID-19 crisis in very different contexts were invited to contribute to this research. Three of these five are members of the GIG network [4]. It is a global network of social and technological innovators that aims to foster the sharing of knowledge and experience amongst members. Two makerspaces are partners of the *Careables* project consortium. In the following list we introduce the representatives of the makerspaces who contributed to this article.

- Brazil: Ricardo Ruiz Freire (Member of the GIG Supervisory Board)

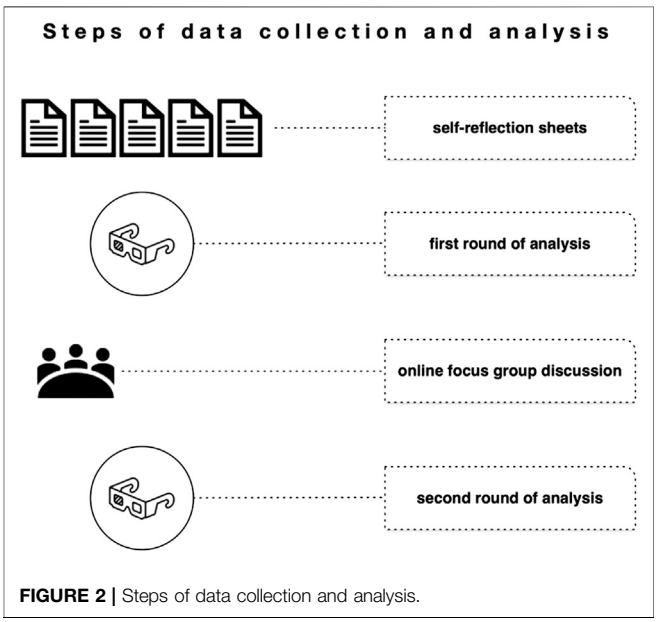

FIGURE 2 | Steps of data collection and analysis.

- Cameroon: Nadine Mowoh (Member of the GIG network)
- Iraq: Nawres Arif (Member of the GIG Supervisory Board)
- Italy: Enrico Bassi (Director of the makerspace OpenDot[5])
- The Netherlands: Paulien Melis (Programme Developer of the makerspace WAAG[6])

In addition to the above-mentioned case representatives four researchers from the *Careables* research team participated in this research. Three of them are female academics at the Center for Social Innovation in Austria, bringing in interdisciplinary perspectives, with an academic background spanning the disciplines of psychology, sociology, pedagogy, and economy. One researcher is a female legal expert working for the KU Leuven Center for IT & IP Law in Belgium. This diversity in backgrounds was important to understand the complexity of the cases and to improve the integration of diverse perspectives through a series of discussions and reflections. The three

[4]https://www.globalinnovationgathering.org

[5]http://www.opendotlab.it/about/

[6]https://waag.org

researchers from the Center of Social Innovation were also the ones who designed this qualitative study and took the lead in analyzing the result.

In general, the overall culture of this research study was collaborative and cooperative, since no single researcher imposed their interpretation, and the results were additionally discussed with all contributors of the paper.

RESEARCH DESIGN

Two data collection instruments were prepared to learn about and analyze the COVID-19 activities in the five cases: a self-reflection exercise and an online focus group discussion (**Figure 2**).

Self-Reflection

For the collection of the data, the research team prepared a self-reflection exercise, which guided the case representatives in their self-reflection process. The self-reflection exercise was based on the following questions, which participants answered in relation to their the COVID-19 response activities of their makerspaces:

- *Case description:* Please describe what were/are your main activities of COVID-19 response. What motivated you to become active as COVID-19 responder? What partnerships/networks/collaborations have you established or are you making use of? How do/did you finance the production of PPE? Where do/did you get the designs from?
- *Perceived impact and achievements:* Please describe the perceived impact that you achieved so far with your activities and what has been the public/political perception of your activities. Has there been any public/political recognition of your contribution? You may also report on the impact achieved by other makers in your community.
- *Barriers and challenges:* Please reflect on the barriers and challenges that you encounter during your COVID-19 activities.
- *Future implications:* Please reflect on the future potential implications that you see from your experiences with regards to post-pandemic local production of healthcare products.

The self-reflection reports, which were filled in by the case representatives during a 3-weeks period in October 2020, were analyzed by the research team in a first round and provided the ground for the structure of the online focus group discussion.

Online Focus Group

The online focus group was organized on November 3, 2020 via the videoconferencing platform ZOOM and lasted 75 min. Representatives from the cases in Brazil, Cameroon, and Italy, as well as the four researchers introduced above, took part and aimed at elaborating a deeper understanding of the described cases and future scaling options.

The starting point of the focus group was a short presentation by the researchers of the three dimensions of social innovation also shared on a Google Jamboard-board and presented in Chapter 3 of this article. After this introduction, the case representatives were invited to place their COVID-19 response initiatives on the respective dimension of social innovation (micro—meso—macro) and explain their decision. In the next step, a second dimension was introduced, the scale and interaction dimension, as an indicator for connectedness (**Figure 3**). This dimension on the vertical axis refers on the one end to a situational awareness, where single actors tend to work relatively isolated, unconnected, and focus on the local area working on very local issues. On the other end of the axis, we speak about distributed awareness, referring to very strongly networked, interconnected makes, who work collaboratively over large areas, or even globally. This matrix of scale and social innovation dimension has been applied in previous studies and has provided valuable insights into the characteristics of maker initiatives (e.g., Unterfrauner et al., 2020).

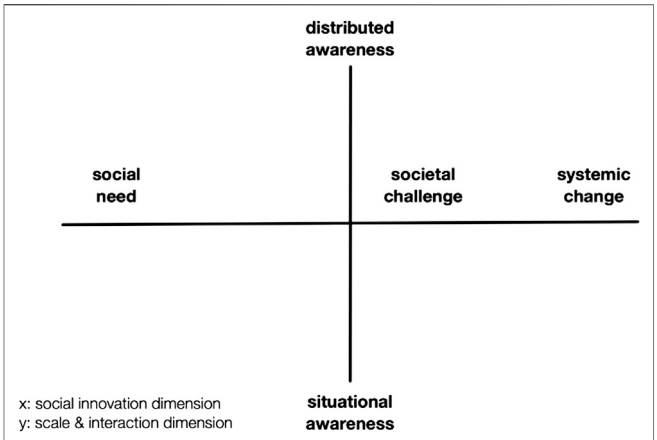

FIGURE 3 | Scale and social innovation matrix (adapted from Unterfrauner et al., 2020).

The case representatives placed again their COVID-19 response initiatives on the respective x- and y-axes and discussed their positioning with the group. After this introduction the core discussion focused on two questions:

- Do case representatives wish that their COVID-19 activities in the different countries scale from micro, to meso, to macro level?
- If not, why not? If yes, under which conditions?

One of the leading researchers facilitated the discussion, while the second one summarized the main aspects of the discussion on the Jamboard to visualize the key points discussed. The third researcher took additional notes. The discussion was moderated to make participants reflect on their cases and to gain themselves new insights into their specific situation. In qualitative research the researcher is not necessarily the invisible neutral, but may also contribute to a moral discourse and spark transformative processes (Flick, 2018). The online focus group was also audio recorded based on the informed consent given by participants, as a basis for the later analysis.

TABLE 1 | Overview of codes, sub codes, and their grouping

Original codes	Sub-codes	Grouped codes
Partnerships	Collaboration	Networks, partnerships, collaborations
Networks (local, regional, National, global)		
Collaboration with healthcare professionals		
Collaboration with educational sector		
Relationship with healthcare sector		
National and international collaboration		
Collaboration with companies and industry		
Collaboration With specific target groups, e.g. police, army		
Coordination of local groups	Coordination	
Coordination of national activities		
Decreasing visibility in large networks	Challenges in networks	
Increased complexity of structured networks		
Not losing contact to local communities		
Lacking Cooperation with government		
Local Context adaption	Local embedding	
Local aspects		
Local coordination groups		
Local needs		
Scaling	Scale	Value, scale, infrastructures
Upscaling		
Shared principles, values	Values	
Voluntary contributions, volunteers		
Political support		
Power of networks		
Fexibility		
Trust		
Sustainability	Sustainability	
Business models		
Funding		
Platforms	Infrastructures	
Local infrastructure		
Communication		
Logistics		
Local supply chains		
National coordination		
Structured Networks		
Overcoming barriers in the production (material, legal and ethical aspects)	Challenges of infrastructures	
Lack of resources, e.g. material		
Lack of funding		
Sensitization	Awareness	Education, training, skills, awareness
Local and international awareness		
Education	Education	
Skills, experiences		
Exchange of knowledge		
Tackeling misconceptions		
Guidance	Training	
Training		
Empowerment of citizens	Skills	
Pushing maker skills towards other domains, e.g. health-sector		
Critical thinking of negative impact		
Safety	Safety	Safety, quality, legal aspects
Quality, certification	Quality	
Prototyping and testing		
Legal aspects (National and International)	Legal aspects	

Analysis and Presentation of Data

The analysis of the case studies is based on the self-reflection reports of the case representatives and the summary of the online focus group discussion. Qualitative content analysis according to Mayring (2014) was selected as a suitable approach for this explorative study. It comprises a holistic and subjective procedure that is used to

interpret and categorize qualitative data. This analytical process makes sense of the data, it describes and highlights important findings and allows to draw clear links between the research objectives and the summary findings. The conventional approach to content analysis (Hsieh and Shannon, 2005) was used here, where researchers avoid using pre-conceived categories, allowing the categories to emerge from the data.

The research material was analyzed through two iterative phases, from October 29, 2020 to November 11, 2020 by the three female researchers from the Center for Social Innovation, who also figure as the first authors of this manuscript. Data were analyzed both inductively and deductively in these two phases. Specifically, two forms of data analysis triangulation were carried out by the researchers to ensure a rigorous and robust approach (Leech and Onwuegbuzie, 2007). First, the self-reflection reports were coded individually by each researcher independently and provided insights about the research material that were shared and discussed. Preliminary codes were then agreed and grouped into sub-codes. The findings from this first coding experience also served as a basis for the focus group discussion, where they were critically reflected with the case representatives. In the second phase of the analysis the original codes were applied to the summary text of the focus groups, first individually by each researcher and then discussed jointly. At the end of this process the following codes, sub codes and a final grouping of the codes was agreed (**Table 1**).

We are aware that this study is exploratory in nature and is giving a rich qualitative view on the reported cases, but is limited in its scope. This is the very nature of qualitative research. Engaging the case representatives in a reflective focus group discussion and being part of the authoring team might shed some doubt on the validity of this research. However, we believe that by doing so we have guaranteed the authenticity of the experiences and our findings are internally coherent. In particular the focus group discussion has helped to reflect on the constructs emerging from the first analytical phase and has allowed the three main researchers to capture data "from the inside" and gain a deeper understanding of the phenomena under discussion (Miles and Huberman, 1994). This transdisciplinary approach was important for a meaningful knowledge co-production as described by Thompson et al. (2017). The integrative and participatory processes during the self-reflection reporting and the focus group discussion opened the complex context of the maker movement for the main researchers. The collaboration of the actors involved in this study, who transcend disciplinary and academic boundaries, has been growing over the years and accumulates in this study. We belief that a certain level of mutual trust amongst all co-researchers is important for the transdisciplinary co-production (Thompson et al., 2017), leading to socially robust knowledge in the sense of Nowotny et al. (2001).

The following case descriptions represent summaries of the self-reflection reports while chapter 6 presents the results from the online focus group.

CASE DESCRIPTIONS

The following five cases of maker responses to COVID-19 cover different perspectives and contexts. Some focus on their lab's activities, some relate more on the national activities all together, and overall, they give a good representation of the diversity of actions encountered in makerspaces across the globe.

The Brazilian Case (LabCOCO, Casa Criatura, Coletivo 3D and LabProComum; Olinda)

In Brazil, before the outbreak of the pandemic, four maker-oriented organizations had established collaborations with the *Careables* project and started to function as local hubs which connect local communities of persons with (physical) healthcare needs, care givers, and public healthcare professionals with the community of makers and medical herbalists. With the outbreak of COVID-19, the activities of these local hubs, called *Careables Olinda*, completely shifted to producing PPE and other medical supplies in order to fight the pandemic. So far, they have produced around 7,000 face shield units out of which they donated around 5,000 pieces to different initiatives, to hospitals and health authorities in the Recife metropolitan area, cities in the countryside, and indigenous and Afro-Brazilian communities. The remaining products were offered via an e-Shop that was specifically set up for that purpose. The Brazilian fablabs partly relied on shared Open Source designs of face shields and adapted them to the local context. Besides, together with healthcare professionals, they developed an open-source model of an aerosol box integrated into local necessities to use at Intensive Care Units (ICU) and released it online. The aerosol box is used in the process of intubation and extubation of patients, to avoid the contact of aerosol sprays of patients with doctors. The product was validated with doctors from two different hospitals in the Metropolitan Region of Recife, who have experience in orotracheal intubation. In addition, a community including professors, medical students and designers from Casa Criatura was established to develop the product further and is, at the time of writing this manuscript, seeking certification and registration of a free patent, with the final aim of bringing the aerosol box to a global market.

Partnerships and networks, local and global, played a crucial role in this case. Since the beginning of its activities, *Careables Olinda* had a dialogue with the Secretary of Health of Olinda, who realized the importance of the maker community in the local production of PPE to keep up the city's health system. Later, collaboration with healthcare professionals and hospitals started as ICU professionals approached the makers with a request for a better version of an aerosol box and jointly they defined the specifications. The relationship with the health sector has allowed *Careables Olinda* to review its area of activity and has expanded the scope of its inventiveness while at the same time it increased local awareness and knowledge about open-source, digital manufacturing and healthcare across the involved stakeholders, e.g., physicists, designers, healthcare professionals, makers. The local maker hubs also felt like being part of a bigger initiative, not only for the producers of PPE. Their communication campaign was a small part of a big operation by different sectors in the cities to suppress the virus and the cooperation with the Secretary of Health has already split over to other activities of open innovation, besides COVID-19.

While the activities clearly showed valuable impact in reducing the curve of COVID-19 infections in the regions (contrary to the figures at national level) and in promoting the social value of open innovation, the actors clearly recognize the negative impact of their actions. The enormous amount of plastic being produced, the considerable degree of pollution and carbon emissions related to the makers' activities, coupled with the environmental problems of the local communities triggered a commitment for more sustainable practices in the future. Some of those have already started to emerge, such as the work with recycled plastic or the creation of a bio-fermentation lab to address the food scarcity in some local communities.

The Cameroonian Case (Mboalab, Mbankomo)

Mboalab is a community biology lab in the central region Yaounde in Cameroon, comprising molecular biologists, biochemists, public communications specialists, microbiologists, and electro-mechanic technicians, who act as educators in the local community to empower the population with the skills to solve their health and environmental problems. During the COVID-19 pandemic outbreak, the lab tried to attack some of the local bottlenecks related to the sanitary situation. The information department at Mboalab accessed the latest information and recommendations from the World Health Organization (WHO), the Food and Drug Administration (FDA), and the Centers for Disease Control and Prevention (CDC), looking for simple formulae for making hand sanitizers and instructions for face masks designs. With their strategy to target the most vulnerable groups and communities (healthcare workers and the local population) of the suburban community of Mbankomo, where the lab is located, they started their educational work. The lab team was able to prepare alcohol-based hand sanitizers that met the FDA recommendation with locally available components and started demonstrating simple formulae for producing hand sanitizers from cheap and readily available components from the local drug stores.

The lab also produced face masks using appropriate local fabric and prototyped an automatic gel and water dispenser to limit the spread of the virus and encourage frequent washing of hands. Educational aspects were embedded in most activities of the lab. Through the use of the automatic gel dispenser the local population was taught about the importance of handwashing and how an effective hand washing exercise should be carried out. These sensitization sessions were also used to educate the population about the Coronavirus, its modes of transmission, ways of prevention–helping to do away with certain myths about the virus that circulated in the local community.

Again, global networks were important to connect with other populations to share stories, knowledge, and approaches using platforms like Openair and Wikifactory. National and international collaboration was encountered in the search of testing kits, and by participating in the development and testing of simple, easy to replicate methods of fighting COVID-19 in resource constraint settings.

In spite of all these efforts made, some challenges were encountered. Upscaling was an issue, due to a lack of funds. For instance, the automatic gel dispenser that was prototyped was intended to be kept in at least 10 major centers of the community to encourage frequent washing of hands and demonstrate an efficient hand washing practice. The general increase in prices of all essential and non-essential goods made life difficult for the common local population. The widely spread belief that Africans are naturally immune to the virus and that some concoctions can provide them stronger immunity and protect them from being infected was another hurdle. Part of the population also strongly believed and went about saying that the Coronavirus is not real and that it was only a scam or some "thing" created to deceive and control people's lives.

Given the sensitizations, training, and collaborations achieved during this period of the pandemic, the population, community biologists, and makers stand a chance of independently handling future pandemics or epidemics by confidently producing PPE or other materials that might be required to fight the pandemic. The approach is to educate and equip the population with the skills to be able to handle the crisis without depending on the government, non-profit-organisations, or foreign aiders.

The Dutch Case (WAAG, Amsterdam)

The maker space at Waag aimed to provide support in maker research, product development and prototyping during the first lockdown phase, teaming up with a nationwide group of Technical Universities, the TechMed Center (University of Twente), the police, the Royal Netherlands Army and national and global maker communities.

In an attempt to better understand the needs within the medical field efforts were mostly dedicated to coordinating and backchanneling within the network. Via online meetings Waag functioned as a catalyst in bringing different maker groups together and has been connecting stakeholders that weren't in contact or collaboration with each other. It was important to get an overview of products or prototypes that were needed most, but also looking into existing solutions or solutions that were being developed, and how Waag could be involved in this. One of the main concerns and also the main challenge for the Waag team was to ensure the safety of the PPE. Also, getting prototypes tested by certified bodies was difficult. Based on the experiences from other makerspaces in the Netherlands and internationally, door handles and face shields were mostly considered for production.

In collaboration with the police Waag explored the prototyping of door handles, which police officers would use when entering an unknown building. Different production methods were explored to find an alternative for the prototype the police were using, which was 3D printed and consumed quite some time for large scale production. The team at Waag adjusted the model so it could be laser cut, and thus be produced at large scale in a short time. The prototype was tested and functional. However, within the police force few police officers wanted to use a door handle in their daily work. So, the adapted design was in the end not produced. Other products the fablab was experimenting with include a transparent face mask and a DIY respirator.

There was a lot of media attention on the lack of PPE for healthcare professionals in the Netherlands. Waag reached out to the medical institutions within the Metropole region of Amsterdam to hear what their needs and wishes were, but in the end the first contacts ended in no specific request for further research or prototyping. Thus, the fablab at Waag started to produce face shields and opened a webshop to sell them at minimal costs to local healthcare professionals, organizations and people working in contact jobs, such as hairdressers, cleaning services, beauticians, nail salons etc. Local residential care organizations that were directly offered these face shields did not show any interest.

Overall, the impact of Waag's engagement has been mainly in coordinating and pushing the notion of maker skills towards other domains, rather than organizing and producing PPE. Building on a network of local, national and international organizations, Waag was able to push the added value of maker skills as a driving innovation force. However, when it comes to the production and distribution of large numbers of products Waag was expecting more collaboration with large enterprises, which was not achieved. According to their experience commercial companies are reluctant to take up on the innovative designs and knowledge stemming from the maker communities.

Finally, it is worth mentioning that the discussion within the national coordination group, including the Netherlands Royal Army, also touched upon the notion of distributed manufacturing. The idea of setting up a global network of decentralized production facilities, as an immediate response to a healthcare crisis, gained wider attention and will be further discussed in the future. Currently the network of fablabs mostly shares knowledge, skills and blueprints, but could it also be equipped to coordinate a large-scale production of e.g. PPE in the future?

The Iraqi Case (Science Camp, Basra)

Science Camp, a maker space based in Basra, south of Iraq, is attached to the global maker movement and used to provide innovative solutions by implementing digital fabrication and DIY concepts, armed with the qualified industrial infrastructure. This space was among the first entities in the country that responded to the COVID-19 crisis with innovative solutions. Approximately 13,000 protective face shields were produced and distributed for free to the frontline medical staff and other main human resources who provide essential services for healthcare, security, delivery services, etc. In collaboration with local industry, local civil society, and academicians, a response infrastructure was set up taking care of e.g. monitoring the needs of PPE, providing raw materials, communicating with healthcare services, PPE production, PPE distribution, online digital statistics monitoring, and research and development. Medical staff highly appreciated the efforts done by the maker community and requested even more face shields and research into other types of PPE.

The design and production process of PPE was adapted to the local context, using locally available raw materials, such as PET plastic sheets used in water packaging factories. Also, the design was adapted to be easy to assemble, with no need for gluing, stapling, or sewing. The digital fabrication techniques applied made the production process use a minimal number of raw materials, and fast, with high quality.

All efforts were covered by voluntary contributions from all partners. The raw materials were a donation from the local water factory. The Iraqi government did, however, not support this type of community response and some international NGOs suggested converting the PPE production process into a business rather than a charity crisis response, which was not realized by the maker space due to ethical reasons.

Apart from the financial challenges, the Iraqi maker space also encountered other difficulties, related to public administration and logistics. Travel permission forms to procure raw materials, machine maintenance, etc. were partly refused during national lockdown and bureaucratic barriers hindered the distribution of PPE via the official channels of the healthcare authorities.

In addition to the high recognition in local and global media, the involved makers got experience in PPE production and legal aspects related to it as well as better insight into the use and availability of raw materials and resources locations. The fast response activities have also shown that the bottom-up social response can work independently from governmental or international aid organizations, avoiding potential conflicts between these organizations.

The Italian Case (Opendot, Milan)

Italy was Europe's first and one of the most affected nations being hit by the COVID-19 pandemic. The country's most efficient health systems in the Northern regions were about to collapse and hospitals were running out of supplies, including PPEs as well as essential parts for ventilators and other respiratory devices. Triggered by the initiative of a maker who provided a hospital with a 3D printer and helped to reproduce missing valves, the value of the maker community for the local health infrastructure became visible, and local supply chains of PPE for healthcare staff and other essential workers started to emerge.

Local coordination groups played an important role in the distributed production and supply chains. These groups were almost all volunteer-based, almost always within existing communities of people or fablab networks who were already used to working together. The first COVID-19 maker networks in Italy were regional, and they succeeded in responding to local needs as they evolved. This teamwork at local and regional levels paved the way for nationwide coordination across Italy. In the period of just a few days, three different initiatives emerged with similar and complementary objectives. One of those initiatives alone, *Make in Italy*[7], collected over 500 contacts from makers, small laboratories, startups and fablabs. Their website currently lists over 25,000 items produced and donated. Opendot, a fablab in Milano, *Careables* partner and specialized in working with the healthcare sector, was involved in the national coordination activities from the onset and contributed to overcoming the local medical supply shortage.

Italy's response to the health crisis wasn't limited to the grassroots maker movement of hundreds of volunteers and fablabs. Many Italian companies worked closely with active makers, and in some cases, even helped the movement to take

[7]http://www.makeinitaly.org/

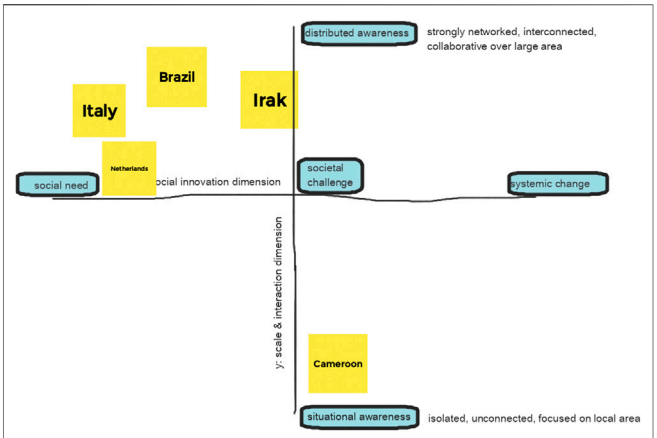

FIGURE 4 | Case positioning on scale and social innovation matrix.

off. Also the educational sector was involved as the face shield production model was included in the training of high school students, initiated by the Maker@Scuola project[8].

The case in Italy has shown so far how new local collaborations for digital social innovations can be established. Because of the emergency, various hospitals contacted specialized studios, fablabs, small businesses and startups in order to develop new solutions together. Doctors have started to become co-designers, innovators and makers. In Italy, we find some isolated examples where these emergency-driven collaborations have turned into established collaborations where hospitals, doctors and therapists recognize the value and potential of digital fabrication tools and distributed local production. However, the organizational and structural details of cooperation between makerspaces and the public healthcare system in a more systematic way are still to be explored.

FOCUS GROUP RESULTS

In the following chapter the results from the focus group discussion with case representatives from Brazil, Cameroon, and Italy are presented.

In a first step, focus group participants were invited to relate their Covid-19 activities to one of the levels of social innovation–the micro, meso, or macro level (see **Figure 4**). The two case representatives not present during the focus group were given an individual explanation of the matrix and were likewise asked for a positioning.

All three case representatives present during the focus group meeting stated that their COVID-19 related activities were in transition from micro to meso level. Thus, cooperation with other organizations became important to meet the social need and not only social but also economic objectives were addressed. The Italian case representative said to have acted on a meso level during the first wave of COVID-19, establishing networks between Italian fablabs and organizations in the need for fabricated health devices; but acted again on a micro level when the emergency situation stopped. Connections with political actors have been established but sustainable links are not in place yet. In the Brazilian case, first sustainable contacts were established with local politicians, who showed interest in the civic engagement taking place in Olinda. Also, the close cooperation with health professionals is still in place, after the first wave. In economic terms, the fablab sells individual face shields, fabricated in their fablab, or whole packages, where e.g., a company is donating 200 face shields. In the Cameroon case the activities were and still are closer to the meso level, as sustainable links to other organizations have been established, mostly related to the educational purpose of the lab.

In a second step, the focus group participants discussed two key questions: 1) If they would wish for their COVID-19 activities to sustainably scale from micro, to meso, to macro level; and 2) if yes, under which conditions.

All three case representatives shared the same opinion–that scaling their activities at least from the micro level to a more stable macro level is wished for, as there are people in the need of help and this need can be met by the production capacities in fablabs. However, scaling up should take place only under certain conditions and building on certain shared principles and values.

Scaling up on the social innovation model should not resemble the scaling up in business terms. It was stated that companies tend to change when they scale, losing contact with local communities, introducing intermediate layers of management, and shifting the focus to financial aspects and maximizing incomes. The risk is that open innovation is not open anymore, but rather owned by a company, thus hindering the innovative groundwork that was originally aimed for by their inventors. So it's fundamental to change the models of scaling up.

Case representatives wish to scale the approach and spread the specific knowledge on how to co-design and produce (personalized) healthcare devices with digital fabrication tools. So training other fablabs in how to support health and care is key here, but also the training of local people–first regarding COVID-19 and how to best protect themselves, and second how to cooperate with and make use of fablabs to support their health and well-being.

Participants aim for establishing connections and collaboration with other fablabs to scale responses to healthcare professionals and people in need. The Italian experience in this regard shows that creating structured networks of cooperation increases complexity. Fablabs are heterogeneous, have different underlying organizational models and specializations. So not every fablab would be able to produce medical equipment that might work properly in a hospital context. The question is how to deal with this complexity and also raises some doubts that strong networks might result in decreasing visibility and importance of the single node of this network.

Legislation issues have to be addressed carefully if medical equipment is the focus of digital fabrication. When producing healthcare products or medical equipment the main aim is to not produce more harm than good. In Cameroon, only certain institutions are allowed to produce medical equipment, thus

[8]http://www.indire.it/en/progetto/maker-at-school/

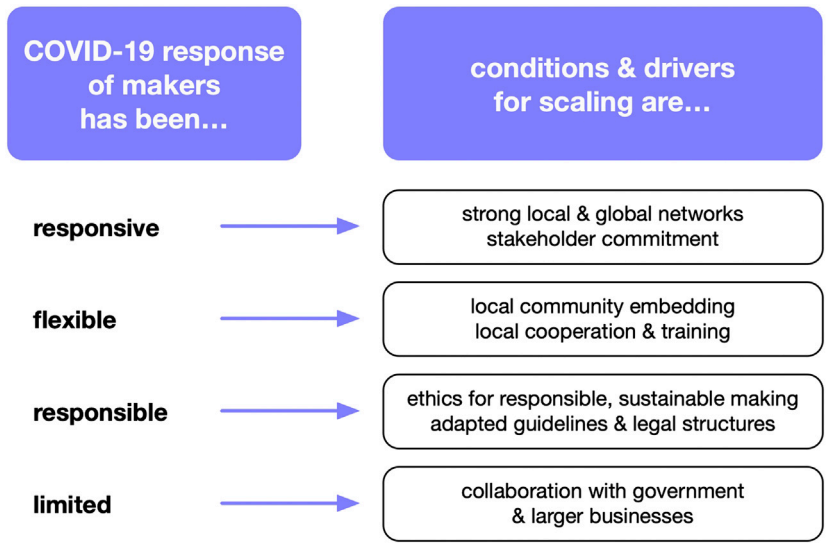

FIGURE 5 | COVID-19 maker response and learnings.

Mboalab focused on producing products where no strict legislative measures need to be addressed, e.g., producing and making accessible proper disinfectants and providing the knowledge on how to protect oneself from COVID-19. In Brazil, legislation is more flexible, and the close cooperation with health personnel allowed the fablab in Olinda to successfully develop face shields used in medical organizations as well as an open-source model of an aerosol box. Nevertheless, *Careables Olinda* stresses that working for other groups in the need of health and care, might be a good way to strengthen their approach while avoiding complex certification issues. In the Italian case, the emergency situation of the first COVID-19 wave gave room for certain legislative exceptions. Still, producing for hospitals requires meeting high quality criteria and demands for additional aspects like documentation, etc. In times of crisis, the official processes might be too long and exclusive to flexibly react to emergencies, so there is a call for more agile mechanisms that are established and tested beyond the times of crisis. It is wished for more flexibility to test the collaboration between medical institutions and local manufacturers to co-design and produce medical equipment below certain risks or costs. As mentioned above, working with and for disabled people, and offering COVID-19 support that is not medical equipment (e.g. disinfection, etc.) are some of the suggested activity areas that can strengthen sustainable cooperation between local manufacturers and people and organizations in need of health and care devices. Alternative approaches to supporting health and care are key to spread the approach.

Additionally, strong local nodes are key to spreading the approach. Working in the health and care sector requires at the one hand trust of people and a diverse set of local organizations, on the other hand it aims to successfully empower local people. Thus, establishing a network of local nodes that adapt to local contexts, link to local organizations and the local community of people in need, is the basis of spreading digital fabrication for health and care.

The COVID-19 emergency situation showed how powerful the network of local digital manufacturers can be in flexibly supporting societal needs. Focusing this power of the network to other aspects, like climate change, digital fabrication initiatives can play a key role in successfully supporting social innovation processes. Maker activities can in this regard catalyze the attention to a wider problem, e.g., the climate change and the scaling up should not take place at the cost of the environment. Thus, producing tons of plastics (e.g., in the case of face shields) should be critically reflected and alternative ways of more environmentally friendly production should be sought.

SUMMARY OF FINDINGS

The two main data collection instruments brought forward complementary findings. While the self-reflection reporting focused on describing the past and current experiences made during the COVID-19 response activities by the makers, the focus group discussion built on these experiences and reflected on future implications for the scaling of the makers' grassroots initiatives. **Figure 5** summarizes the experiences made by the cases and the learnings and implications these experiences reveal for a potential scaling in the future.

From the collected experiences we see how fast the maker community reacted during the health emergency by supplying local healthcare providers with urgently needed PPE and other medical devices. Such **responsive** behavior was strongly enabled by the commitment of local stakeholders on the one hand and the global connectedness on the other hand. By drawing from their local, national and global networks the actors in the makerspaces were able to get rapid access to design templates, material resources and distribution channels. Some of the connections

with relevant stakeholders, such as medical staff or local politicians, proved to be rather fragile though. For scaling locally embedded maker activities that address local social needs a strengthening of networks, locally and globally, is important according to our cases.

The COVID-19 response of the makers was also **flexible** in adapting to the local contexts. This resulted in localized designs, such as the Brazilian tropical face shield, which was a local adaptation of a German design, or the use of locally available materials, such as the Iraqi PET plastic sheet, which are usually used for water packaging. In the case of the Cameroon maker space the COVID-19 response activities included a strong educational aspect acknowledging the local need for more information about the virus. Next to the importance of education and training on maker skills, the cases also highlight the strong local embedding and connectedness to the local communities as essential for a flexible and fast response to pressing social issues. For a future scaling of maker space activities that respond locally to social needs established cooperation with local stakeholders has been identified as a key element.

Another important aspect addressed in the self-reflection and the focus group discussion has been the awareness for a **responsible** practice from makers. Across the five cases we observe a strong sense of social responsibility. This has been manifested in acknowledgment of quality standards for healthcare products as well as the overall commitment to doing no harm and user safety. Clear guidelines and legal structures that allow responsible making are thus being requested based on the current experiences. When discussing ethical aspects, the case representatives also stress their growing awareness towards the need for ecologically sustainable maker practices.

Finally, the case representatives are aware of the **limitations** of the approach. Their COVID-19 response activities were limited in terms of capacities, resources, and infrastructures. The makers thus recognize the boundaries of what can be achieved within their limited spaces. Collaboration with established businesses and governments should be envisioned for the future. This would allow for an effective response at a larger scale.

DISCUSSION

The five cases represented in this study are located across three continents and are embedded in very different contexts, economically, politically, and socially. When the COVID-19 pandemic started to spread, these makerspaces took on the challenge of counteracting the PPE and medical device shortages. In their civic reactions to the failures of public healthcare procurement and shortages in the global supply chains, they all faced some similar challenges and new opportunities. In this analysis, we want to concentrate on four main perspectives that evolved during the analysis and turned out to be relevant when discussing the maker COVID-19 response activities in the theoretical frame of the three social innovation levels: social needs (micro level), societal challenges (meso level), and systemic changes (macro level).

(1) A Network Perspective

Working in translocal networks, referring to networks at local and global level, has been a critical aspect for the operation on the ground. We saw that reflected in all of the cases, with local networks playing a key role in all phases, from research and design to the production, testing and distribution of the provided COVID-19 response solutions. The established local networks and temporary partnerships include stakeholders from across the quadruple helix, namely academia, government, civil society, and industry. In addition, in most cases, the fast reaction from the makerspaces was only possible due to the global open sharing of PPE designs. Being globally connected offers access to a wide range of resources and is possible only in a culture of openness and sharing, which is propagated also by the Open Design and Open Hardware movements. The benefits of open networked collaborations become visible immediately in times of crisis, such as the COVID-19 pandemic. In social transformative innovation theory translocal networks are an important element contributing to empowerment (Avelino et al., 2019). From the reported experiences in the five cases, we can consider maker communities as local and global networks that exchange resources, experiences, and knowledge at global level, but act at local level to adapt to the specific contexts and react to local needs. This ability and commitment for open global collaboration and mutual learning is described as one of the unique features of the global maker movement (Smith, 2017) and also implies a certain ethical commitment of the contributing makerspaces. The cases contributing to this study confirm their potential for empowerment as suggested by (Avelino et al., 2019) and resilience of the local actors, similar to what has been encountered by Wuyts et al. (2020).

The sustainability of the emergent translocal networks is however very fragile. The Italian case showed that highly efficient and quickly established networks might become loose when the emergency situation is over. For the networks to continue and possibly lead to a transformational change as described by Avelino et al. (2017) new objectives for collaboration that foster a sustainable linkage between network members are needed. For future emergency situations these flexibly emerging translocal networks and partnerships, that have already been installed in previous situations, might help to react even faster.

(2) A Value Perspective

An ethical commitment of the makerspaces becomes noticeable also in other aspects. When discussing ways to scale their practices a need for new types of business models and new value definitions was expressed. Transformative social innovations cannot be achieved by just applying existing innovation models and capabilities to issues of social concern (Smith, 2017). It needs a redefinition of values (Avelino et al., 2017) and a redistribution of innovation capabilities. Globally distributed local manufacturing processes need to be assessed on a different level than large enterprises. Next to the purely economic value, which is still dominating in the

entrepreneurial context and also present in many maker space activities, we need to appreciate other values, often social and ecological values, that are associated with local experimentation and small-scale production in makerspaces. The ecological footprint of manufacturing is a concern for many makers as we have seen documented e.g. in the Brazilian case. We can deduct that we find within the activist approaches of makers an environmental conscious reflection and self-critical view on their material productive engagement as confirmed by others (e.g. Smith, 2017; Richterich, 2020). Wuyts et al. (2020) likewise recognize the value of maker activities during the pandemic in moving towards a more circular economy in the healthcare sector.

With the presented experiences we argue that environmentally and socially responsible making should be assigned additional value, next to the cost-benefit calculations dominating today's business models and move to added value-oriented models. The case representatives in this study follow a community-driven approach, not a business-driven approach, which needs higher societal recognition. There are attempts to raise broader attention for the values of transformative social innovations in measurable terms, such as the Social Return on Investment (SROI), which is a performance measurement tool, demonstrating the social value enterprises generate. SROI is however an underused and undervalued practice despite being accepted as an internationally recognized measurement tool for social enterprise (Millar and Hall, 2012). For community-driven approaches in makerspaces new value models for scaling are needed as the makerspaces of this study clearly do not want to follow the prevailing economic model of scale dominated by monetary value.

(3) An Educational Perspective

Makerspaces are often characterized as spaces for collaboration, information sharing, reflection and learning (Sheridan et al., 2014). Incidental as well as intentional learning takes place in these settings as they are often linked with creativity, collaborative problem solving, digital competence, and entrepreneurship (Vuorikari et al., 2019). An educational agenda was stressed in the Cameroon case, where an important objective of the lab's COVID-19 response activities was to educate the local population in terms of hygiene measures. The other case representatives emphasized the importance of education in their activities generally, and specifically in terms of scaling social innovations.

Also, learning between makerspaces and with and from other network partners, like health professionals, is key. We see knowledge exchange on a global scale that addresses overarching topics, like the exchange of certified, proven PPE instruction guides, guidelines on the design of co-creation processes, and the efficient use of digital fabrication tools. And we can identify contextualized knowledge that emerges in the diverse settings, like how to react to the local availability of material, how to adapt production processes to local contexts, how to address very specific local needs. Undoubtedly, the learning taking place in makerspaces leads to empowerment and resilience (Criado et al., 2016; Unterfrauner et al., 2020). As Ratto (2011) identified learning as core in his critical making theory, where the process of making is as important as the results, we also suggest that more societal recognition could be added to the educational value created in makerspaces. Critical skills acquired during the material exploration contribute to the empowerment of the individuals as well as the community. Again, we see similarities here to the cases of empowerment analyzed in detail by Avelino et al. (2017). Learning and practicing new skills in social spaces are key elements for empowerment and contribute to the transformative potential of social innovations.

(4) A Legal Perspective

In order for local manufacturing to become relevant at a systemic level, fundamental transformations of the underlying structures need to take place. In the context of open healthcare, current legal frameworks are one of the key structures that would require adaptation. As system changes are typically slow and require long-term thinking, makers are exploring the current boundaries in their support of the healthcare sector. Part of the current boundaries being explored by makers relate to the nature of the solutions they produce. In some states (e.g. in the European Union) the production of specific solutions–such as respiratory valves or breathing masks–requires complex processes and compliance documentation. These are necessary as the solutions qualify as medical devices and imply the respect of the relevant laws in the matter (Medical Devices Directive, 1993, in the European territory). While the role of these regulations is to ensure a high level of patients' safety and protection, they set approval mechanisms and controls that are not always compatible with emergency situations. In some countries, competent authorities allowed for emergency use authorization for certain technologies (Food and Drug Administration, 2020). As Pearce (2020, p. 12) noted, many regulatory roadblocks remain across several countries, which may need to be improved to allow rapid response and provision of medical supplies in healthcare emergencies.

A second kind of boundary relies on liability mechanisms for makers in the context of emergency situations. As illustrated in the introduction, in a known case some makers reverse-engineered the design of a respiratory valve to face a product shortage in an Italian hospital, which led the original manufacturer to threaten bringing legal action against them for intellectual property infringement. This example explicates the difficult value balance between the perceived need to act (even "ethically") by makers vis-a-vis the possible unintended negative consequences of such ethical acting. As a way forward, so-called *Good Samaritan Laws*–which offer protection from liability for those whom they believe to be in peril, ill, or otherwise incapacitated - could set useful measures to counterbalance this dichotomy. This legal perspective could help reduce the barriers for companies and makers hindering the release of healthcare projects' designs and their replication. The case of COVID19 opened new scenarios for the application of these laws. We are aware of the complexity of system innovation as they are "profound transformations in social systems" (Grin et al., 2010) and we believe that we are still far from seeing innovations being fully implemented in our current legal systems, but the recent

experiences during COVID-19 have started to challenge the current boundaries. Thus, future exploration, both in research and by policymakers is needed (Pearce, 2020) and it would be capable of opening new perspectives for the makerspaces and the role of makers.

CONCLUSION

The experience brought forward in our five contextually very different cases has shown how local production networks can function in times of emergency. Their local design, production, and distribution of PPE and other healthcare related products towards health professionals and the general population has proven to flexibly cover emerging needs and stand in for global manufacturers. Looking at the makers' initiatives during the COVID-19 crisis from a social and transformative innovation perspective, we encounter a wish to scale from working on the social needs level to addressing wider societal demands and, in the future, even triggering systemic change. Networking and sharing knowledge and experiences across multiple actors are key with this aim. Representatives from the five cases stress the importance of emergent translocal networks for their COVID-19 response to happen, which include actors of the quadruple helix on local scale while exchanging and learning from each other globally.

Scaling transformative practices of makerspaces is however envisioned only under certain circumstances and following a set of principles and values. A commitment towards openness and sharing, such as it is propagated by the open hardware movement, requires new forms of business and value models. Prototyping in the healthcare domain, with and for patients, people with disabilities, and other often vulnerable groups, requires an ethical commitment and legal backing in order not to produce more harm than good. Educational and environmental considerations likewise come into play. Empowerment through teaching and creating only solutions that address real personal problems or needs are core principles of responsible making. In the makers' future endeavors towards co-designing and making open, personalized healthcare and establishing these processes as social innovations more social value propositions may be encountered, with implications for individuals, communities and society at large. While we notice signs of empowerment at individual and community level, we envision a strengthening of democratic processes at society level. Other scholars likewise speak about the democratic value of makerspaces, which they find in certain grassroots activities that address social issues (e.g. Taylor et al., 2016; Willingham, 2017; Sipos et al., 2019). At the same time, we are aware of the critical views some scholars express towards makerspaces. Lindtner et al. (2016) challenge the democratization potential of the maker movement and suggest a more self-critical and reflexive approach for the whole community of makers. We hope this study can contribute to the discussion.

We have considered implications that go beyond the makers' response to fighting COVID-19 from the experiences made in five contextually diverse settings. We are aware of the limitations of our study, but see reasonable generalization justified by the contextual heterogeneity of the cases covered, the strong embeddedness and connectedness of the case representatives (and co-authors) with the global maker community, and the similarities we have found on other documented cases, such as those documented by others. Our case-based snapshots resonate well with other documented experiences (e.g. Diez and Baeck, 2020; Richterich, 2020). Next to this qualitative approach a more systematic and quantitative assessment of the impact that the maker communities worldwide had on fighting the COVID-19 pandemic is needed. In how far has the global maker response during the COVID-19 emergency situation created sustainable impact and have longer-term linkages between local manufacturers and health care services been created? Also, we would love to see more explorations of how and under which conditions makerspaces contribute to addressing societal challenges and how these may trigger systemic change in the future.

DATA AVAILABILITY STATEMENT

The raw data supporting the conclusions of this article will be made available by the authors, without undue reservation.

ETHICS STATEMENT

Written informed consent was obtained from the individual(s) for the publication of any potentially identifiable images or data included in this article.

AUTHOR CONTRIBUTIONS

BK is the main author and added the abstract, the state-of-the-art sections, case study descriptions, discussion and conclusion, study design was done by BK, TS, and CF; CF described the methodology and prepared the images based on discussions with BK, TS described the focus group outcomes and contributed to the discussion and conclusion, EnB provided the parts of the legal analysis, all others contributed with filling in the self reflection reports and ElB, RR, NM, and EnB participated in the focus group, which was led by BK and TS; CF was the note taker.

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Telework and Lifelong Learning

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The increase of telework during the pandemic is predicted to impact working life, not only in terms of a larger number of employees working from home, but more importantly, it may transform the way we conceptualise work. This will in turn impact systems for and participation in lifelong learning. There is a risk for increased social inequalities, as neither telework nor lifelong learning is evenly distributed among workers. Statistics on telework in the EU show that there are differences between age groups, nations, sectors, and professions. If these trends will steer forward, there is a risk of widening gaps between countries, companies, and workers. To establish the current knowledge base, we have gathered literature reviews from several disciplines. One finding is that the previous literature on telework has not included lifelong learning in any form (formal, non-formal and informal). Based on a review of previous studies, we suggest a number of research questions for future research. This is relevant as research about telework and lifelong learning has the potential to contribute to a sustainable working life in terms of providing more flexible arrangements for employees and to support the lifelong learning that takes place in contexts such as the office, home, online meetings, and virtual reality.

Keywords: lifelong learning, sustainable working life, social inequality, telework, telecommuting

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INTRODUCTION: INCREASED TELEWORK AND INCREASED SOCIAL INEQUALITIES

In 2020, telework has become the new normal in working life. Considering employees in the EU between the ages of 15 and 64, an average of 5.4% worked from home in 2019 (Eurostat, 2020). These numbers have been similar for 10 years. However, the number of people who work from home a few days a week has increased during the same period, from 5.2% in 2009 to 9% in 2019. Among the self-employed, almost one in five worked from home. There are differences between men and women and between different ages. Slightly more women than men worked from home (5.7 vs. 5.2% in 2019). Moreover, the proportion of people who work from home increases with increasing age. Among people in the 15–24 age group, 2.1% worked from home, while among people in the 50–64 age group, 6.6% worked from home. (Eurostat, 2020).

However, all these figures are from the time before the pandemic, and the proportion of people working from home has increased disproportionately. In Sweden, it increased tenfold, and among white collar workers, two thirds have worked from home since the pandemic struck in 2020 (Internetstiftelsen, 2020). Most people who have been working from home are satisfied, while those who have studied at a distance are dissatisfied (ibid). Although working from home may not remain to the same extent as the pandemic subsides, it is likely that we will see an increase compared to the figures from 2019. Not least, the proportion who will combine work remotely with presence in the workplace may increase. However, the ability to choose and combine workplaces is not evenly distributed between professions and positions. The rapid changes in working life also raise the question of competence. In Sweden, a land often ranked as highly digitalised, a survey showed that during the last year, 49% have felt that they have insufficient digital knowledge both in the labour

market and privately (SVT, 2021). In the World Economic Forum's "Future of jobs report 2020", it is estimated that around 40% of workers will require reskilling of six months or fewer, and a staggering 94% of business leaders expect employees to pick up new skills on the job, compared to 65% in 2018. The needed skills include analytical skills as well as skills in self-management, such as active learning, resilience, stress tolerance and flexibility (WEF, 2020). Self-management skills are innately connected to telework, as it is a situation that requires more responsibility from the employee in terms of managing the physical and psychological work aspects, as well as performing the work itself. To support a sustainable working life, in light of this year's changes linked to telework, the following insights presented by the European Commission (2020) can guide efforts:

- There are large differences in the prevalence of teleworking between EU Member States, between sectors and between professions.
- The readiness to implement teleworking on a large scale is high in IT and knowledge-intensive sectors and for the highly educated, but there are large differences between countries.
- In many EU countries, more than half of those who now work remotely had not tried it before.
- If previous trends will steer forward, the risks of widening gaps between countries, companies, and workers are great.

Although most people expect that they will return to the workplace after the pandemic, it is highly probable that the number of people teleworking will increase to some extent, and this will change the conditions for working life in several ways. Not only will it change the social dynamics of workplaces, but we also need to discuss the dissatisfaction among people in distance studies in connection to competence development and upskilling. There is a risk that efforts of improvement, such as the provision of flexibility through telework or lifelong learning through education and training, will be unevenly distributed among professions and sectors. There is, because of this, a risk for increased social gaps in society. When it comes to the relationship between teleworking and lifelong learning, there are at least two ways to approach this connection. Firstly, one can focus on the individual's perspective and how teleworking affects formal, informal and non-formal lifelong learning. Secondly, the focus can be on lifelong learning as policy, where an important message is that everyone should have the opportunity to participate in society on equal terms.

Based on the assumption that telework will increase compared to the frequency of teleworkers before the pandemic, and the fact that there is an urgent need for new skills, the aim of the paper is to review previous research on telework. The review is guided by the research question: What can be concluded about telework based on previous research, with regard to efforts for competence development and upskilling as part of the individual's lifelong learning? In this paper, we will make a synthesis of reviews addressing telework to find out what we already know about the impact on lifelong learning, including competence development. Based on this, the discussion addresses possible consequences that teleworking might have for an individual's lifelong learning and proposes questions for further research. The paper is based on a multidisciplinary and broad understanding of telework, as suggested by Allen et al. (2015), to fully understand the benefits and drawbacks of working from home.

TELEWORK: AN OVERVIEW

In 1973, Jack Nilles' book *The Telecommunications-Transportation Tradeoff* introduced the term telecommuting to discuss distance working as a solution to traffic congestion and pollution. A decade later, companies saw telework as a tool to reduce the expense for office space, but this has shifted again into telework as a strategy to attract and retain top personnel (Kurland and Bailey, 1999). During the pandemic, employees have called attention to the risk that employers (again) might see telework as a tool to reduce expenses for office space. However, what has been raised in research, as discussed below, is that telework might require investments from the employer to achieve the desired benefits. Therefore, the cost structure might be different, but it should not necessarily be understood as primarily a cost-cutting strategy. Kurland and Bailey (1999) defined four types of telework:

- *Home-based telecommuting* refers to when employees on a regular basis work from home, but they are based at a central office belonging to an employer.
- *Satellite offices* refer to work locations situated at a convenient location allowing employees to cut the time they spend commuting. This branch office is furnished and equipped by the employer.
- *A neighbourhood work centre* is like a satellite office, with the exception that several employers share the lease of the building and it may have a site owner responsible for the location.
- *Mobile workers* are employees who work in an assortment of locales, such as from home, from a car, from a plane, or from a hotel.

Telework can thus take place in different contexts, but when telework is researched, the focus is usually on home-based telecommuting. According to the four types of telework presented by Kurland and Bailey (1999), telecommuting is a form of telework; in later papers, however, there is often no separation between telecommuting and telework when addressing working from home. The concepts telecommuting and telework are used interchangeably in this paper.

When looking at who participates in telework, why they do it and what happens when they do, Bailey and Kurland (2002) find that telework is a complex concept and phenomenon, although in research, the focus is often on one or a few parameters. In their review, they established that the individual teleworker was a nearly universal focus of study and that there were assumptions that telework took place on a full-time basis. Furthermore, Bailey and Kurland highlighted that, apart from methodological weaknesses, the studies lacked awareness of

TABLE 1 | Advantages of telework on the individual and the organizational level.

Advantages with home-based telework	References
Individual advantages: less time consuming, cost savings, less stress, no need for relocation, more autonomy, schedule flexibility, comfortable work environment, fewer distractions, absence of office politics, work/family balance, workplace fairness, and more job satisfaction. Organizational advantages: greater productivity, lower absenteeism, better morale, greater openness, fewer interruptions at office, reduced overhead, wider talent pool, lower turnover, and regulation compliance (e.g., disabilities act).	Kurland and Bailey (1999)
Individual: Higher job satisfaction, higher organizational commitment, less pressure, better time management, reduced travel time, balanced work and home life, distraction-free environment, less involvement in office politics, suitable for homebound employees. Organizational: increase productivity, lower costs, less office space needed, reduced absenteeism, lower turnover, do not have to have all employees in one location (a terrorist consideration), increased recruitment options, and able to adapt to the virtual organization.	Crandall and Gao (2005)
Telework is environmentally friendly, telework can create more flexible work arrangements and at the same time help to lower the costs of running office premises, telework can be a way of raising the company's corporate image, changeover to telework has improved job control and well-being at the individual level and increased the overall efficiency of organizations.	Pyöriä (2011)
Individual: Savings based on less travelling and type of clothing, possibility to coordinate for work-life balance, spatial mobility beyond commuting distance, increased work autonomy, increased job satisfaction, and increased productivity. Organizational: Recruitment and retention, increased work morale, productivity gains, improved agility, and financial advantages such as cost savings for office rent.	Boell et al. (2013)
Increased perceptions of autonomy and lower work–family conflict; good quality of employee–supervisor relationship; job satisfaction; lower turnover intent and role stress; higher supervisor ratings. These beneficial consequences appeared to be at least partially mediated by perceived autonomy.	Gajendran and Harrison (2007)

TABLE 2 | Challenges of telework on the individual and the organizational level.

Challenges with home-based telework	References
Individual challenges: Social isolation, professional isolation, organizational culture, reduced office influence, work/family balance, informal interaction, conducive home environment, focusing on work, longer hours, access to resources, and technological competence. Organizational challenges: Performance monitoring, performance measurement, managerial control, mentoring, jealous colleagues, synergy, informal interaction, organization culture, virtual culture, organization loyalty, interpersonal skills, availability, schedule maintenance, work coordination, internal customers, communication, guidelines (e.g., expenses), and technology.	Kurland and Bailey (1999)
Individual: Feelings of isolation from the work culture, lack of promotional opportunities, loss on the assignment of good projects, dissatisfaction with peer relationships, less influence over the people and events at work, work/family conflict, and harder to take a sick day. Organizational: More difficult to supervise, assessment concerns, special logistics requirements, sensitive information could be compromised, goes against the concept of teamwork, control over health and safety, and lack of infrastructure support (secretary, etc.).	Crandall and Gao (2005)
The importance of agreeing on a framework for telework, telework does not suit everyone, the problem of a traditional management culture, teamwork, and data security.	Pyöriä (2011)
Individual: Work-life blurring, lack of socializing opportunities, questions about career, less workplace involvement, reduced trust, lack of technical support, and unwanted interruptions. Organizational: Management practices do not fit the situation, legal framework is not sufficient, hinders teamwork and collaboration, lack of relevant expertise and training, infrastructure, and technology outside the office, data security, and investments in telework costs.	Boell et al. (2013)
High-intensity telecommuting (<2.5 days a week) harmed relationships with co-workers.	Gajendran and Harrison (2007)

issues of status and power. Although the demographics of teleworkers are elusive, the teleworking population may be divided along occupational and gender lines. Later reviews and frameworks for studies on telework list similar advantages and challenges of telework (Crandall and Gao, 2005; Pyöriä, 2011; Boell et al., 2013). In **Tables 1**, **2**, lists of advantages and challenges from reviews of telework are presented. The collection is not complete; for example, the list in Crandall and Gao (2005) is based on Baruch (2001) and Daniels et al. (2001). This description of previous research will provide a background to the discussion on lifelong learning and telework.

The advantages for the individual are that telework provides flexibility and autonomy. High autonomy is a factor supporting evidence for home-based telecommuting as an employee-oriented human resource practice (Hornung and Glaser, 2009). Workers who can use telework to adjust tasks to meet their needs and desires are more likely to be satisfied, and telework is more positively related to firm performance than

other dimensions of labour flexibility (Martínez-Sánchez, et al., 2008). Less time spent commuting provides more time for other activities. The individual has more job control and opportunities to manage the work-family balance. To be in control could be one explanation for other positive outcomes, such as less stress, job satisfaction, and well-being. Fewer interruptions when working and cost savings are also mentioned as advantages. An empirical study of 102 employees from a large United States government agency reported that employees experienced more job-related positive affective well-being when teleworking compared to when working in the office, but the individual differences moderated this relationship (Anderson et al., 2015). The discussion focuses on the need to consider the affective consequences of telework and the characteristics that determine who will benefit from working at home. Telework before the pandemic was in some cases regarded as a reward, a perspective that could explain positive notions of telework (Gajendran and Harrison, 2007).

The organizational advantages are increased productivity and increased work morale. That telework is perceived to improve performance, increase productivity, and strengthen organizational commitment was supported in an analysis of empirical studies on telework and organizational outcomes (Harker Martin and MacDonnell, 2012). Fewer interruptions and cost savings are also mentioned as advantages for the employer. Access to a wider talent pool creates advantages for recruitment, and retention of personnel provides stability in operations. Regulations compliance is supported, and the Disabilities Act is mentioned as an example of this. Telework is sometimes presented as a way for employers to work with inclusion and diversity perspectives, but this is an area where more research is needed. In a literature review with a focus on work-life balance for workers with disabilities or workers who have family members with disabilities, the authors found a total of only 48 articles over 20 years (Igeltjørn and Habib, 2020). The review indicates that although several articles imply that policies could have positive effects on the work environment of home-based teleworkers, they do not describe how this could be achieved or whether existing policies have yielded the desired effects.

Telework also presents challenges, listed in **Table 2**. In reading these challenges, the reader should be reminded of the meta-analysis of psychological mediators and individual consequences performed by Gajendran and Harrison (2007) that provided evidence against the telecommuting paradox in variables listed as advantages AND challenges (for example, family-work conflict). There are thus contradictions between the studies referenced in this paper, and we want to raise awareness of the methods used and how they impact what is studied, how findings are presented, and the relevance of results in relation to practical situations. Therefore, continued analyses and various ways to study the details of telework are still needed, not the least during and after the pandemic situation.

The challenges for the individual when teleworking can be social and professional isolation, with less influence and involvement in matters that are dealt with at the office. The negative emotional impact of teleworking can come in the form of emotions such as worry, irritability, guilt, and loneliness (Mann et al., 2000; Mann and Holdsworth, 2003). Detachment from work is described as a career risk, as the individual might miss out on opportunities when not being at the office in person. Limited access to organizational resources and ergonomic issues in the home environment are other drawbacks. Work–family balance was an advantage, but it can also be a challenge, depending on the individual's situation. The challenges for the organization concern management activities, such as monitoring, measuring, and controlling employees' outcomes. This "problem" should, however, be viewed in the light of findings stating that telecommuting availability was directly and indirectly related to engagement via perceived supervisor goal support, and that the option to telecommute could increase employee engagement (Masuda et al., 2017). Control over health and safety, including data security, are challenges when employees work from home. Pain or discomfort stemming from telework could be addressed with teleworker ergonomics training. A study found that almost half of the participants experienced physical problems, but 85% of the participants had not received ergonomics training (Harrington and Walker, 2004). A challenge for both the organization and the individual is lack of informal interaction, which has consequences for the development of interpersonal skills and mentoring opportunities.

Crandall and Gao (2005) included an outlook on unresolved and emerging issues that are necessary to include for a complete understanding of telework conditions. The first unresolved issue concerns the role of the organization and government in establishing employee safety when working from home. In many countries, the employer has an obligation to maintain a safe working environment regardless of where the work activity is performed. When it comes to telework situations, questions about insurance coverage and responsibility may arise because of blurred boundaries. The second unresolved issue addresses whether telework is a way for the organization to exploit workers. Two main targets have been identified in this debate: women and less skilled workers. These connect back to previous research findings that it is relevant to include occupation and gender to understand differences in the teleworking population (Bailey and Kurland, 2002). Whether telework is a form of exploitation directed at women remains speculative; however, it is highly probable that telework can contribute to increased polarization in working life and that this polarization could be along gender lines (Crandall and Gao, 2005). The third issue that Crandall and Gao (2005) suggest for discussion is the use of technology, as this is a field in rapid development. According to the desktop metaphor, telework relies on a standard set of technology such as PC, e-mail, etc., but the virtual reality metaphor is emerging as an alternative. Virtual reality potentially offers increased social richness and a feeling of "being there" (that is, being at the office). Technology, and the emergent new society connected to technological development, enables telework in new ways. However, in the information society, it is increasingly difficult to define or demarcate working hours and places of work and to distinguish between commodity and service production (Pyöriä, 2011). Hybrid work set-ups call for new human resources and management practices

with regard to how social space and territoriality play out (Sewell and Taskin, 2015).

From the organizational point of view, the individual as well as the task dimension are relevant to understanding how to plan telework. This requires considering professional differences as well as task differences. Writing a memo could fit telework, whereas activities requiring physical coordination between colleagues require office presence. The type of work done may provide clear or blurred boundaries between work life and private life, and therefore not all professions have the same potential for telework (Hislop and Axtell, 2007). Bailey and Kurland (2002) suggested that future research should expand the lens beyond individual teleworkers to include the practice that telework affects, to consider why people work away from the office and include the option that telework may be a way to cope with the demands of the modern workplace, and lastly, to emphasise theory-building and connect links to organizational theories.

The individual dimension of telework discussed above is on an overall level. Several authors pointed to the fact that individual differences may influence the perception and outcome of telework. Factors such as family structure, living space and technological equipment constitute the conditions for telework. Age and experience could be relevant to understanding telework and could be connected to the ability to structure work efforts at home. When workers value the status associated with telework, or if telework satisfies needs for achievement and stimulation, it may be easier for organizations to allow larger proportions of their workforce to telework, as these values can motivate teleworkers to perform their tasks in line with organizational goals (Peters et al., 2016). Pyöriä (2011) pointed out that telework is suitable for jobs that require peace and concentration and in jobs that require creative problem-solving skills, where the option to work flexibly according to need and inspiration is vital (Pyöriä, 2011). The idea of the creative problem-solving professional being flexible to live and work anywhere and anytime stands in contrast to the tendency for knowledge workers to concentrate in and around economic hubs. Additionally, we are reminded that the notion of what technology can do for us often takes on mythological dimensions:

"The idea of the empowered teleworker has become highly charged symbols, in some instances a clear myth, incorporating an overtly optimistic vision of the almost limitless possibilities that ICTs have to offer" (Pyöriä, 2011, p. 387).

To implement telework as a practice in working life should furthermore give attention to the proper recognition of interests from unions, as labour representatives. In Europe, trade unions have discussed, for example, the burden of costs when working from home, occupational safety, ergonomics, and work hour arrangements, as part of formal frameworks for telework. Kurland and Bailey (1999) indicated that one risk with telecommuting is that worker solidarity decreases when telecommuters are physically dispersed and less able to organize collectively, which may affect the work of unions. The decreased orientation towards other workers may also be a problem for teamwork and thereby for learning:

"Additionally, managers may find it difficult to create team synergy and to overcome the absence of informal, interactive learning—learning that takes place by the water cooler, over lunch, or in the hallways" (Kurland and Bailey, 1999, p. 59).

The problem with telework is that interaction and communication often take place as scheduled meetings, which does not support learning in the same way as the informal interaction in the office does. This spontaneous learning cannot be scheduled, but it is nevertheless an important part of the individuals' development, sometimes called "in place career development". A specific part of this learning is to master interpersonal skills that may be needed to interact, communicate, and cooperate with colleagues, customers, students, and others as part of working. With a substantial part of the workforce working for a considerable amount of time from home, this could change the nature of social intercourse in unknown ways. Taskin and Bridoux (2010) have highlighted that teleworking could endanger an organization's knowledge base and competitive advantage as the knowledge transfer between teleworkers and non-teleworkers is threatened. Apart from mentioning the risk for knowledge drawbacks, lack of informal learning, and the need for ergonomics training for teleworkers, the issue of competence development and lifelong learning is absent in the literature on telework, despite the recognition of new ways to conceptualise work, which may demand learning and require new theoretical frameworks as well as practical knowledge for individuals, organizations, and societies.

TELEWORK DURING THE PANDEMIC AND LIFELONG LEARNING

The lack of research on how telework affects lifelong learning, competence development, and upskilling is problematic, and in addition to this, we now have the current situation with a pandemic changing our everyday lives, including how and where we work. While telework used to be a tool to make employment more attractive, it has currently become a measure to stop infection. When telework is performed by people who do not want to work from home and may have limited experience doing so, this will most likely change our understanding of telework. Similar to how 9/11 changed airport security jobs across the globe, the pandemic will change jobs in ways that we have yet to understand (Li et al., 2020). Moreover, families are locked up together in their homes, raising issues of places for the whole family to work and study, and whether the internet connection can handle several virtual meetings taking place in the same home. As people were forced to work from home when the pandemic hit in 2020, they were at the same time forced to learn. This meant that a massive digital competence boost took place, which provided insights into the need for HR practitioners and managers in general to understand the needs of teleworkers and provide adequate support. As mentioned in the introduction of this paper, people also learned that they did not have sufficient digital skills to manage everyday tasks in life and work.

Furthermore, we have not seen the full effects of actions taken and the impact of changes on our understanding of telework and

the transformation of employees into remote workers. So far, the premises have been similar for all, regardless of age, gender, and level of expertise, although there is a big difference between people working in professions that can be performed at a distance, as opposed to those who have to be at work to perform their tasks. Compared to the few veterans already working from home, the newbies, individuals with limited experience of working from home (Li et al., 2020), had to master virtual meetings, online software, e-learning tools, and more during a short period of time.

"The reality is that most newbies have been forced to learn fast how to stay at the top of the game and ensure that they have the knowledge to follow the veterans. They have to engage with online forums, amend work documents, undertake online meetings, share resources, and make the argument online. They simply try to figure out what they have to do and, in many cases, without any support" (Li et al., 2020, p. 201).

Even though some learning that took place came in the form of competence development courses that were quickly developed by the organizations or by learning institutions, the lion's share of the learning that took place concerned informal learning driven by concrete needs for solving problems. To talk of learning instead of education is not without consequences because it emphasises the individual's development instead of the institutional context within which it may take place. This also entails a shift from the subject content to the human aspects that are involved; we move from merely teaching a subject to considering a person's development (Jarvis, 2007). This idea is based on two fundamental principles for lifelong learning:

- Learning must be understood as a complete whole and as an interaction between the individual and their surroundings. When lifelong learning is part of the public debate, much is spoken about what the individual must learn in terms of specific competencies. In such a case, according to theories about lifelong learning, there is a lack of dialogue about what it is that gets the individual to engage in learning. In contrast to policy initiatives that base this on external driving forces (for example, a demand for certain competencies within a particular industry), in life-long learning, the question that is asked is: What is it that creates real interest in learning in the individual?
- The individual's identity process is central to learning. Theories about lifelong learning claim that this includes a new understanding of oneself. In short, learning entails a renegotiation of one's identity. For example, for many adults, learning about the digital world (that we live in) entails a significant adaptation with respect to their identity. An example of this is when a teacher, who may be an expert in the classroom, is a mere beginner with respect to the digital world. To understand learning in practice, one should ask the following question: What effect does participation in learning have on the person's perception of themselves?

These two points are theoretically grounded (Wenger, 1998; Illeris, 2004; Jarvis, 2004, Jarvis, 2007, Jarvis, 2012; Illeris, 2017), but they also provide practical advice with regards to arrangements for adult education initiatives. When the labour market calls for competence development and upskilling, most often, it does not consider the individuals who are affected by this; instead, focus is placed on the benefits that the employer hopes to reap from such efforts. To move forward, one might ask: What is it that creates true enthusiasm in people? What internal effects does learning have on people? Are there structural and mental spaces within the organization for the individual who undergoes change through education? These are important questions for the person who wishes to support lifelong learning, and they are important to set in relation to the telework context. Based on the foundation set out here by lifelong learning theories, the following section provides a set of questions and ideas to guide research that could contribute to theoretical as well as practical knowledge.

FUTURE RESEARCH ON TELEWORK AND LIFELONG LEARNING

The reviews summarised above do not specifically address competence development or lifelong learning. Kurland and Bailey (1999) stated that one challenge for managers was that telework led to a focus on outcome rather than the process. Telework often means that a manager cannot see when employees are struggling and step in with reliable and constructive performance feedback. The situation of the manager who works with formative feedback is similar to that of a teacher, and the balance between focus on output and process in competence development at work should be addressed in future studies. Hybrid forms of work arrangements may be connected to new power structures, and the roles and responsibilities of managers as well as employees may evolve. To understand complex entanglements and to approach new, visible, and not visible challenges and changes in telework, socio-material approaches provide opportunities for insights (Boell et al., 2013; Sewell and Taskin, 2015). Spatial mobility and temporal flexibility change the nature of work itself, work processes, and human engagement. The development of virtual realities (VR) is often presented as a way to achieve increased social richness (Crandall and Gao, 2005), but we do not yet know what the impact of virtual realities will be on learning in a telework setting. Suggested research questions are:

RQ1: How does changed interaction patterns between manager and employee impact formative feedback in the organization?
RQ2: How will hybrid forms of work arrangements interplay with competence development in organizations?
RQ3: What does informal, non-formal and formal learning mean in a telework context?
RQ4: How will telework change in the a) nature of work, b) work processes, and c) human engagement influence individuals' lifelong learning?
RQ5: How can the social richness in virtual realities compensate for the relational disadvantages of telework?

In the telework literature, flexibility and autonomy of workers are often presented as challenges, as they stand opposed to the need for teamwork and collaboration in the organization (Boell et al., 2013). This contradiction between autonomy and coordination may, however, be a chimera based on the idea that teamwork needs to be led by a manager. Self-organized teamwork could work well in many professions and may even be more effective than top-down management in several cases. Contact between team members based on emergent problems in the work process could be considered a strong key to informal learning, as learning at work is often problem based. This is an area where we need future studies to validate this proposition. Context and interaction are two key concepts in lifelong learning theories, and the challenges with interaction in telework, combined with context entanglements, propose that we may need to study telework in innovative ways to obtain the full picture.

RQ6: How will the balance between autonomy and teamwork influence individuals' learning and competence development?
RQ7: How do individuals engage in the self-organization of learning, and what kind of support do they need from the organization?
RQ8: How can problem-solving initiatives in the individual's daily work be enriched by reflection, and how is this included in a relevant way?

When telework some decades ago became an option for many due to the development of technology, there were hopes that telework would help organizations decrease real estate costs, promote a healthy work–family balance, aid compliance with Disabilities Act, and reduce air pollution and traffic congestion (Bailey and Kurland, 2002). What we have observed through the literature review results is that the advantages presented have not been realised to the extent that was expected. The cost for telework is not simply reduced, but investments in the home office are needed to avoid negative effects on the employees' health. As a form of flexible work arrangement, however, telework has a natural place in today's working life. Rather than considering telework and telecommuting as an option to working at the office, it should be regarded as a practical flexible arrangement that can boost productivity without resulting in social exclusion or jeopardizing crucial interactions with colleagues (Pyöria, 2011) and that can be used differently depending on the task and on the individual. The individual's expectations and possibilities can be a starting point when setting up plans, but the organization should have knowledge about what is possible and why they are doing it.

RQ9: How can telework support an inclusive approach to learning and competence development?
RQ10: What kind of investments are needed to improve skills for and through telework?
RQ11: How do organizations embrace individuals' expectations and possibilities to support lifelong learning in telework?
RQ12: What kind of organizational strategies are emerging concerning telework, and how do they include learning and competence development?

Before ending this section, it might be appropriate to remember that early research on telework proposed that telework could be a way to reduce traffic congestion and pollution—the environmental gains when people work from home. The hopes of an improved environment are still relevant, and research during and after the pandemic can shed some light on whether telework has changed the condition of our natural environment. This paper has, however, highlighted the need to recognize telework as an environment for learning. This is also important, as we need knowledge in this area to be able to support a sustainable working life where people thrive and can make robust contributions to companies and society.

CONCLUSION

There are increased needs for competence development and upskilling due to the digitalization of our everyday lives, but digitalization also enables telework solutions of various kinds and with new tools. While telework and lifelong learning are usually discussed in positive terms, we want to raise attention to the fact that participation in both telework and lifelong learning is not evenly distributed in the population. This has become obvious during the pandemic where, for example, professions with a critical societal function, such as employees in health and social care, have not been able to telework. The transition to, and appreciation of, telework is probably highest among educated white-collar workers who already may have had some experience of telework and who are interested in participating in further development. Differences between age groups, nations, sectors, and professions should be kept in mind when formulating telework and/or lifelong learning practices and policies. If not, there is a risk of increased social inequalities between countries and between individuals.

The review in this paper has shown a lack of research on lifelong learning in all its forms (formal, non-formal and informal) in telework. Research about telework and lifelong learning has the potential to contribute to a sustainable working life in terms of providing more flexible arrangements for employees and to support the lifelong learning that takes place in different contexts (office, home, virtual, etc.). As there are expectations of an increase in telework, full-time or in hybrid solutions, after the pandemic has subsided, it is relevant to increase the knowledge about lifelong learning practices in this area.

DATA AVAILABILITY STATEMENT

The original contributions presented in the study are included in the article/Supplementary Material, further inquiries can be directed to the corresponding author.

AUTHOR CONTRIBUTIONS

All authors listed have made a substantial, direct, and intellectual contribution to the work and approved it for publication.

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Global Healthcare Resource Efficiency in the Management of COVID-19 Death and Infection Prevalence Rates

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The scale of impact of the COVID-19 pandemic on society and the economy globally provides a strong incentive to thoroughly analyze the efficiency of healthcare systems in dealing with the current pandemic and to obtain lessons to prepare healthcare systems to be better prepared for future pandemics. In the absence of a proven vaccine or cure, non-pharmaceutical interventions including social distancing, testing and contact tracing, isolation, and wearing of masks are essential in the fight against the worldwide COVID-19 pandemic. We use data envelopment analysis and data compiled from Worldometers and The World Bank to analyze how efficient the use of resources were to stabilize the rate of infections and minimize death rates in the top 36 countries that represented 90% of global infections and deaths out of 220 countries as of November 11, 2020. This is the first paper to model the technical efficiency of countries in managing the COVID-19 pandemic by modeling death rates and infection rates as undesirable outputs using the approach developed by You and Yan. We find that the average efficiency of global healthcare systems in managing the pandemic is very low, with only six efficient systems out of a total of 36 under the variable returns to scale assumption. This finding suggests that, holding constant the size of their healthcare systems (because countries cannot alter the size of a healthcare system in the short run), most of the sample countries showed low levels of efficiency during this time of managing the pandemic; instead it is suspected that most countries literally "threw" resources at fighting the pandemic, thereby probably raising inefficiency through wasted resource use.

Keywords: pandemic, COVID-19, death rates, infection rates, recoveries, data envelopment analysis, healthcare systems efficiency, technical efficiency

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INTRODUCTION

Since it first emerged in China in late December 2019, the new coronavirus (COVID-19) spread to nearly every country of the world (1). Within 7 months, it had spread to 215 countries and regions. At the time of producing this paper, on November 11, 2020, 52 million people were known to be infected (2), and ∼1.3 million deaths had been recorded since the outbreak. Countries adopted pandemic spread mitigating interventions referred to as non-pharmaceutical interventions (NPIs), such as social distancing, testing and contact tracing, case isolation, and public hygiene at

an unprecedented scale (3). Without a proven vaccine or cure, non-pharmaceutical interventions including social distancing, testing, wearing of masks, and contact tracing are essential to end the worldwide COVID-19 (4).

Even with these drastic NPI interventions, the spread of the pandemic exploded, especially with surges in contagion experienced in countries like Italy, France, the UK, and the USA. This put immense strain on the availability of especially intensive care unit facilities, doctors, and nurses, and the efficiency of healthcare systems was also put under the spotlight. What we learn from recent experiences in the fight against this deadly disease from countries like South Korea is that accessibility to healthcare services can significantly reduce the number of deaths (5). Moreover, Sarkar et al. (4) used a mathematical model to demonstrate that the elimination of the ongoing SARS-CoV-2 pandemic is possible by combining restrictive social distancing and contact tracing. They concluded that the accurate course of the epidemic heavily depends on how and when quarantine, isolation, and precautionary measures are enforced. This is also supported by Breitenbach et al. (6). According to Khajanchi and Sarkar (7), in the absence of specific antivirals or vaccines, mathematical modeling plays an important role in better understanding the disease dynamics and in designing strategies to control the rapidly spreading infectious disease. Samui et al. (8) used a compartmental mathematical model to predict and control the transmission dynamics of COVID-19 pandemic in India with epidemic data up to April 30, 2020. They computed a basic reproduction number, R0, of 1.7. This showed a substantial outbreak of COVID-19 in India. Their model predicted that, for about 60 days, the peak will be higher for COVID-19 infections in India and after that the curve will plateau, but the coronavirus disease will persist for a long time.

It is for this reason and the impact of COVID-19 on society and the global economy that the efficiency of healthcare systems needs to be thoroughly examined. This could inform appropriate policy responses and adequately prepare health systems to respond better to future pandemics. Our study is different from typical compartmental models as we address the issue of macro-efficiency of public healthcare systems by applying data envelopment analysis (DEA), a non-parametric and mathematical model adept to estimate the technical efficiency of public healthcare systems. We also use extensive data compiled from Worldometers (2) and the World Bank (9–11). Specifically, we analyze the efficient use of available resources to stabilize the rate of infections and minimize the case fatality rates in the top 36 selected countries representing 90% of global infections and deaths in 220 countries as of November 11, 2020. Our contribution to the literature is 2-fold: first, this paper is the first to model the technical efficiency of countries in dealing with the COVID-19 pandemic by modeling death rates and infection rates as undesirable outputs and, second, by modeling comparative scenarios to test the accuracy of our model. Modeling contagion curves and estimating efficiency rates may contribute to policies and strategies to assist public healthcare systems in the fight against this pandemic. However, the role of media is invaluable in educating the population about the dangers of the pandemic and the importance of using NPIs. This can potentially change the publics' behavior and affect the implementation of individuals' intervention and control strategies (12).

LITERATURE REVIEW

DEA has been applied extensively to compare the efficiency of healthcare facilities within countries and between countries, and we briefly deal with some of that literature here. We do not deal with the literature on country studies because our paper compares efficiency between countries. For literature on efficiency studies among different healthcare facilities within a country, see, for example, Ngobeni et al. (13), Campanella et al. (14), Alhassan et al. (15), Jarjue et al. (16), Chowdhury et al. (17), Gannon (18), Marschall and Flessa (19), Akazili et al. (20), Masiye (21), Zere et al. (22), and Kirigia et al. (23, 24).

Although healthcare is one of the most popular areas of application for DEA (25), DEA studies on healthcare systems worldwide are still limited. For example, Bhat (26) used DEA to measure the impact of financial and institutional arrangements on national healthcare system efficiency in 24 OECD countries. Lo Storto and Goncharuk (27) applied DEA to measure the technical efficiency of 32 European (EU) countries. Afonso and St Aubyn (28) used a two-stage DEA to estimate a semi-parametric model of the healthcare systems in 30 OECD countries for the years 1995 and 2003. De Cos and Moral-Benito (29) estimated alternative measurements of efficiency using DEA and stochastic frontier analysis between 1997 and 2009 to ascertain the most important determinants of healthcare efficiency across 29 OECD countries. Hadad et al. (30) compared the healthcare system efficiency of 31 OECD countries with two model specifications, one including inputs under management control and the other including inputs beyond management control. Kim and Kang (31) used a bootstrap DEA to estimate the efficiency of healthcare systems in a sample of 170 countries.

Although the choice of inputs is similar in these studies, outputs selection depends mostly on the purpose of the research. For example, Gonzalez et al. (32), in a cross-sectional study, measured the technical and value efficiency of health systems in 165 countries. They used expenditure on health and education as inputs and data on healthy life expectancy and disability adjusted life years as health outcomes. Examining the efficiency in healthcare services delivery to the population, Bhat (26) uses the number of populations aged 0–19, 20–64, and 65 years or older as outputs. Santos et al. (33) examine the efficiency of countries in preventing the mother-to-child HIV transmission and used the number of pregnant women tested for HIV and the number of HIV pregnant women receiving antiretroviral drugs as outputs.

DEA studies for new settings such as the recent COVID-19 outbreak may however need to introduce new outputs. Shirouyehzad et al. (34) uses DEA to analyze the efficiency of contagion of COVID-19 and focus on the number of deaths and recoveries as outcomes. Breitenbach et al. (6) analyze the 31 most infected countries during the first 100 days since the outbreak of the COVID-19 coronavirus for the efficiency in containing the spread of the virus and focus on flattening the curve as the

main output. Empirical work pivots mostly on healthcare system performance based on technical efficiency calculated as a ratio of some quality-of-life variable as an output and physical health resources or expenditure on health as inputs. The inputs mostly used were expenditure, doctors, and nurses, while the outputs were discharge or recovery, prevalence, and mortality rates. In this paper, we use tests, doctors, and nurses as physical inputs and health spending as financial input in managing the COVID-19 pandemic. As outputs, we use case fatality (deaths) and infection prevalence rates.

METHODOLOGY

In this paper, we use the variable returns to scale (VRS) approach reported by Gavurova et al. (35) and developed in 1984 by Banker, Charnes, and Cooper (BCC model) to allow for consideration of scale efficiency analysis. Envelopment in DEA refers to the ability of the efficiency production frontier to tightly enclose the production technology (input and output variables). According to Cooper et al. (36) and McWilliams et al. (37), DEA was developed in a microeconomic setting and applied to firms to measure the efficiency of converting inputs into outputs. In the analysis of public institutions, firms are replaced by the more encompassing decision-making units (DMU). DEA is therefore an appropriate method of computing the efficiency of institutions employing multivariate production technologies. Aristovnik (38) and Martić et al. (39) distinguish between input minimization and output maximization DEA models. The former determines the quantity of inputs that could be curtailed without reducing the prevailing level of outputs, and the latter expands the outputs of DMUs to reach the production possibility frontier while holding the inputs constant. However, the selection of each orientation is study specific. In this paper, we select input minimization orientation, as the objective of the study is to measure the efficiency of resources used (minimized inputs) at prevailing health output levels (recovery, death, and infection rates). It is unwise to select an output maximization dispensation as it would be tantamount to maximizing death and infection rates as desirable outputs alongside the recovery rate. When undesirable outputs are an inevitable by-product in the production process, the input minimization orientation is selected as the preferred DEA [also see You and Yan (40)].

According to Taylor and Harris (41), DEA is a comparative efficiency measurement tool that evaluates the efficiency of homogeneous DMUs operating in similar environmental conditions, for example, DMUs dealing with COVID-19 and where the relationship between inputs and outputs is unknown. We follow Joumard et al. (42) to treat the whole healthcare system in a given country as a DMU in order to analyze the healthcare system at the aggregate level. We also adopt the VRS methodology in this study because of heterogeneity among the DMUs in terms of factors like country size and income. In terms of the DEA methodology, the current study uses the BCC model, with the ratio of DMUs being four times the combined number of inputs and outputs to ensure the stability of the efficiency results.

Modeling Undesirable Outputs

DEA models have found increasing use in efficiency analysis applications where at least one output in the production process is an undesirable output, e.g., pollution. There is considerable research published on the undesirable aspects of production outputs. However, You and Yan (40) have found that the economic implications and the suitability of DEA models incorporating the undesirable outputs should be carefully considered as the results may either under- or overstate efficiency if modeled incorrectly.

The first way that undesirable outputs are dealt with in the traditional DEA model is to ignore the undesirable output (43–46). It is not, however, appropriate to ignore the reality of, e.g., pollution during production since undesirable outputs and desirable outputs are generated simultaneously in the production process. Dyckhoff and Allen (47) dealt with undesirable outputs by modeling them as inputs. However, treating undesirable outputs as inputs fails to reflect the true production process. There is a specific production technology that links inputs to outputs, and taking an undesirable output as an input in the production process leads to misspecification and misinterpretation, for example, when modeling pollution as an input using an output-oriented measure, ecological inefficiencies remain undetected. Golany and Roll (48) suggested a data transformation approach where an undesirable output is converted into a "normal" output by a monotonic decreasing function. The undesirable outputs (carbon and nitrogen emissions) are treated as normal outputs by taking their reciprocals. Although the pollutant is treated as output, the scale and intervals of the original data get lost, and the problem with zero values is that it does not have a reciprocal value. The linear monotonic decreasing transformation was suggested by Seiford and Zhu (49). A sufficiently large positive scalar β_i is added to the reciprocal additive transformation of the undesirable output i so that the final values are positive for each DMU_k. This model is criticized for its invariance to data transformation within the DEA model (45, 46). Färe et al. (50) treats undesirable factors in a non-linear DEA model based on the weak disposability of undesirable outputs (51). Weak disposability assumes that, to reduce undesirable outputs, it is costly because simultaneously it increases the inputs or decreases desirable outputs (52). It tends to increase the desirable and undesirable output concurrently. Regardless of the form of transformation, as long as the final value of undesirable output included in the DEA calculation remains positive, it increases the efficiency of the DMU. An undesirable output should bring either a negative or positive impact to the performance of the DMU; therefore, it is not appropriate for the undesirable output to solely favor the efficiency score.

After comparing the performance of the models discussed above, You and Yan (40) developed the ratio model, which outperformed all five of these models developed for dealing with undesirable outputs. We therefore opted to adopt the ratio model for the current paper. The ratio model is different from the previous approaches in that the undesirable output is aggregated in a ratio form with the desirable output.

From the conventional BCC DEA model and assuming that there are R DMU_r ($r = 1, 2, \ldots, R$) that convert m inputs to

n outputs, DMU_k is one of the R DMUs being evaluated. It is further assumed that DMU_k consumes m inputs X_t^k ($i = 1, 2, \ldots, m$) to produce n outputs Y_j^k ($j = 1, 2, \ldots, n$), and all these outputs are assumed to be desirable. The measure of efficiency of DMU_k is then obtained by:

min θ subject to

$$\sum_{r=1}^{R} \lambda_r X_i^r - \theta X_i^k + s_i^- = 0 \qquad i = 1, 2, \ldots, m \quad (1)$$

$$\sum_{r=1}^{R} \lambda_r Y_j^r - s_j^+ = Y_j^k \qquad j = 1, 2, \ldots, n \quad (2)$$

$$\sum_{r=1}^{R} \lambda_r = 1$$

$$\lambda_r, s_i^-, s_j^+ \geq 0 \qquad r = 1, \ldots, R \quad (3)$$

where DMU_r = the rth DMU, $r = 1,2, \ldots, R$; DMU_k = the kth DMU being evaluated; X_i^r, Y_j^r = the inputs and outputs of every DMU_r; $i = 1, 2, \ldots, m$, j = 1,2, . . . , n; θ = the efficiency of DMU_k; λ_r = the dual variable corresponding to the other inequality constraint of the primal;

s_i^-, s_j^+ = the slack variables that turn the inequality constraint into an equal form; $\lambda_r^*, s_i^{-*}, s_j^{+*}$ = the optimal solutions when the relative efficiency of DMU_k is $\theta^* = 1$ and $s_i^{-*} = s_j^{+*} = 0$.

In the ratio model, the undesirable output and desirable output are defined as O_q^- ($q = 1. 2, \ldots, n_1$) and O_p^+ ($p = 1, 2, \ldots, n_2$), respectively ($n_1 + n_2 = n$). For DMU_k, the undesirable outputs $O_q^-(q = 1, 2, \ldots, n_1)$ are treated as a new variable ψ_k, which is called the penalty parameter and is written as:

$$\psi_k = \rho_1 O_{1k}^- + \ldots + \rho_{n1} O_{n1k}^- \quad (4)$$

where ψ_k = penalty parameter for DMU_k; ρ_q = the penalty for individual undesirable output ($q = 1, 2, \ldots, n_1$); O_q^- = the undesirable output ($q = 1, 2, \ldots, n_1$). Since ρ_q is the penalty charged for producing the outputs, the ψ_k obtained from problem (10) gives a measure of the total monetary value of undesirable outputs. From the definition of ψ_k, the greater the amount of undesirable output, the greater is the value of the penalty parameter. Furthermore, the respective value of ρ_q is associated with the individual undesirable output; therefore, ρ_q has the same value for every DMU. With this model, desirable and undesirable outputs can relate to one another, regardless of a disagreement in units. With the new approach of treating the undesirable outputs in Equation (10), the desirable output p ($p = 1, 2, \ldots, n_2$) of DMU_k in the ratio model is modified as:

$$Y_\rho^{'} = \frac{1}{\psi_k} O_p^+, \qquad (p = 1, 2, \ldots, n_2) \quad (5)$$

where O_p^+ = the desirable output $(p = 1, 2, \ldots, n_2)$, and $Y_\rho^{'}$ = the modified output $(p = 1, 2, \ldots, n_2)$.

The ratio model computes desirable and undesirable outputs as fractions, where undesirable output O_q^- is the denominator and desirable output O_p^+ is the numerator. Here the value of the output is interpreted as a ratio of desirable to undesirable output. Using ratios provides a simple and easy way to expose the impact of undesirable outputs in a DEA. The ratio form of the DEA model can satisfy the restrictions of the conventional DEA, which the output variable states must be a positive value. Moreover, the ratio form provides a more distinct way for the desirable and undesirable output to describe the presence of an undesirable output on DMU efficiency.

In order to check the stability of our model results, we ran three different model specifications and compared the results. In model I, we use the number of tests and number of doctors and nurses as physical inputs, health expenditure as financial input, and the ratio of recoveries to infection rates as output (ratio of desirable to undesirable output). In model II, we use the number of tests and number of doctors and nurses as physical inputs, health expenditure as financial input, and the ratio of recoveries to death rates as output (ratio of desirable to undesirable output), and in model III, we use the number of tests and number of doctors and nurses as physical inputs, health expenditure as financial input, and the number of recoveries as output. In model III, we therefore ignore the undesirable outputs (43–46). Although it is not good to ignore the undesirable outputs of the rate of new infections and death rates, we do this in order to compare the difference that the inclusion of the undesirable outputs in our model has on the efficiency scores.

Data

Our data were gathered from different sources. The COVID-19-related data (i.e., infected cases, recovered cases, deaths, and number of tests) were extracted from extensive data compiled from Worldometers (2). The aggregated data on doctors and nurses per 100,000 of the population and healthcare expenditure were obtained from world development indicators provided by the World Bank (9–11). As reported earlier, we analyze the efficient use of available resources to stabilize the rate of infections and minimize the case fatality rates in the top 36 selected countries (see **Table A1**) representing 90% of global infections and deaths in 220 countries as of November 11, 2020.

Some descriptive statistics of the variables reported in **Table 1** indicate that our sample countries have, on average, resources of nearly seven doctors and nurses per 1,000 of the population, a budget of about 8% of gross domestic product (GDP) and 200,850 tests per one million of the population for its healthcare system. The number of infected cases and deaths from COVID-19 over the study period averaged more than 1,295,120 and 32,821, respectively, and the mean number of people recovering from the infection was around 974,487 persons. Assuming that the whole healthcare system is mobilized to fight the COVID-19 outbreak, how efficient was the mobilization of resources? This issue is analyzed with our DEA model, and the results are reported in the next section.

RESULTS

The results of the three model variants are graphically illustrated in **Figure 1**, and the results are presented in **Table 1** (**Table A1**). As intimated earlier in this paper, it is important to consider

TABLE 1 | Descriptive statistics and variables used in the model.

Variables	No. of observations	Unit	Mean	Standard deviation	Minimum	Maximum
Physical Inputs						
No. of Tests	36	per million of the population	200,849.78	159,220.81	15,033.00	541,193.00
No. of Doctors & Nurses	36	per 1,000 of the population	7.00	5.00	1.00	22.00
Financial Input						
Health Expenditure	36	% of GDP	8.00	3.00	3.00	17.00
Desirable output						
Recovery Rate	36	No. of People	974,486.67	1,844,065.41	30,504.00	8,023,412.00
Undesirable output						
Death Rates	36	No. of People	32,820.67	50,619.93	1,174.00	245,989.00
Infection Rates	36	No. of People	1,295,119.31	2,265,355.91	175,711.00	10,575,373.00

Authors' calculations based on Worldometers (2) and The World Bank (9–11).

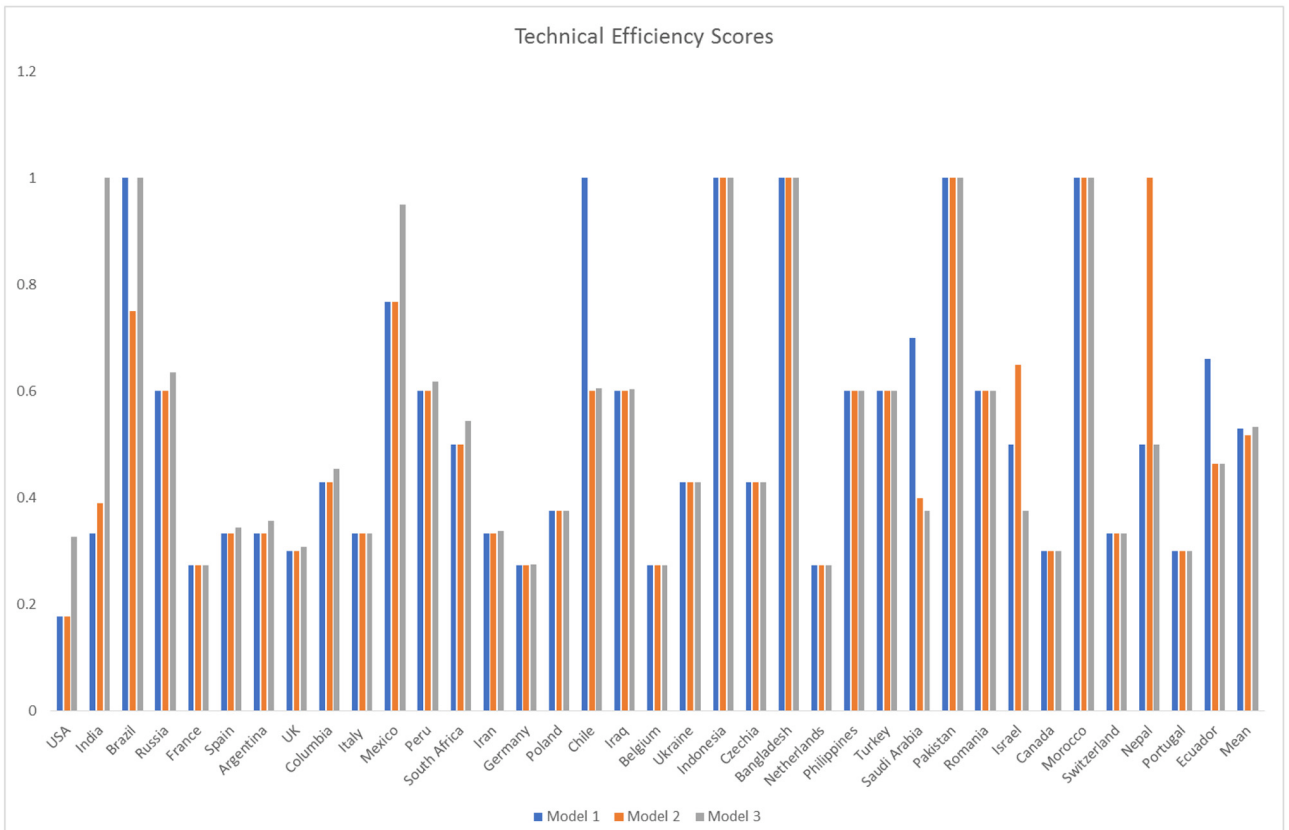
the VRS technical efficiency scores motivated by the differences in the size of healthcare systems globally, particularly between large developed economies and small less-developed economies. The VRSTE scores are almost identical across the three model variants. This points to two things: first, the inclusion of undesirable outputs in our model (variants I and II) does not have any material impact on the mean technical efficiency of country healthcare systems and, second, it points to the stability of our results across the three model variants. For the sake of simplicity, we therefore discuss only the results reflected in model I, where our physical inputs were the number of tests/million of the population and number of doctors and nurses per 100,000 of the population and our financial input healthcare expenditure as a percentage of GDP and our output recoveries/infections. Under the CRS assumption, there were only two efficient healthcare systems in dealing with COVID-19, *viz*., Bangladesh and Pakistan. When the VRS assumption is considered, the figure rises as expected, in this case to six, with the addition of Brazil, Chile, Indonesia, and Morocco.

These differences, regarding the full sample of 36 countries, are statistically significant under a Mann–Whitney–Wilcoxon's test ($Z = 5.271$, $p = 0.001$). It indicates the role of scale efficiency in our analysis because it is the objective of global healthcare systems to achieve the optimal technical combination of the inputs to produce the outputs, but their scales (sizes) are not optimal yet. Although 21 of the 36 countries in our sample are operating under increasing returns to scale, the technical combination of inputs to produce the existing output is still not optimal. Six of the 36 countries operate under decreasing returns to scale (see the **Table A1**), suggesting that they can double their inputs without doubling their output. These countries could therefore rationalize their healthcare resources/inputs by downsizing (using resources/inputs more efficiently) and, thereby, improving the technical efficiency, while the outputs can still stay the same. At first glance, it is often difficult to envisage a country with a large undesirable output to be technically efficient. Brazil, for example, has a very high number of infections and deaths, yet our DEA results show that Brazil is technically efficient and lies on the efficiency frontier. To gain further insight into this number and the associated DEA efficiency scores, it is helpful to compare inputs and outputs of a benchmark country like Brazil relative to that of other countries. We have done this in **Table 2**.

For example, in comparison to Brazil, the USA spends 4.25 times more as a percentage of GDP on healthcare, has 3.5 times more doctors and nurses per 100,000 of the population, and had 471% more COVID-19 tests performed relative to Brazil, yet it did not succeed to contain its undesirable outputs (infections are 185% higher and deaths are 151% higher than Brazil) even though it performed well in the area of the good output—recoveries. This result clearly explains the relatively low VRS technical efficiency scores of the USA, France, Germany, and Belgium in **Table 2**, which could be linked to the specific policy responses of the selected countries. For example, evidence now suggests that the UK failed to fight the COVID-19 outbreak by following a "herd immunity" approach (53), and the USA was very slow to act against COVID-19 (54).

CONCLUSIONS

This paper examined the efficiency of 36 healthcare systems (which represent 90% of cases globally) in managing the COVID-19 pandemic, given their resource constraints. We use a novel DEA approach, developed by You and Yan (40), which accounts for both desirable outputs (recovered cases) and undesirable outputs (infections and deaths), and our results indicate that the average efficiency of global healthcare systems in managing the COVID-19 pandemic is very low, with only six efficient systems out of a total of 36 under the variable returns to scale assumption. This finding suggests that, holding constant the size of their healthcare systems (because countries cannot alter the size of a healthcare system in the short run), most of the sample countries could not improve their efficiency during this time of managing the pandemic; instead it is suspected that most countries literally "threw" resources at fighting the pandemic, thereby probably raising inefficiency through wasted resource use. Inefficient countries could learn best practices of managing pandemics from the efficient countries in the sample, most being developing countries. This indicates to the global



	Model I: Output - recoveries/infection			Model II: Output - recoveries/deaths			Model III: Output - Recoveries		
	CRSTE	VRSTE	SE	CRSTE	VRSTE	SE	CRSTE	VRSTE	SE
Mean	0.43	0.53	0.76	0.3	0.52	0.51	0.14	0.53	0.22
Standard deviation	0.27	0.256	0.233	0.266	0.244	0.27	0.235	0.256	0.258
Maximum	1	1	1	1	1	1	1	1	1
Minimum	0.03	0.18	0.11	0.01	0.18	0.03	0	0.27	0.01
No. of Efficient	2	6	10	2	5	2	2	6	2
No. of Inefficient	34	30	26	34	31	34	34	30	34

FIGURE 1 | Constant returns to scale and variable returns to scale efficiency scores of global healthcare systems. $CRST_E$ represents technical efficiency under constant returns to scale assumption, $VRST_E$ represents technical efficiency under variable returns to scale assumption, and SE represents scale efficiency.

TABLE 2 | Inputs and outputs relative to the benchmark country (Brazil).

Country	VRSTE	Expenditure (% of GDP)	Doctors & nurses/100,000	No. of tests	Infections	Deaths	Recoveries
Brazil	1	4	4	102,766	5,701,283	162,842	5,964,344
USA	0.18	17	14	484,227	10,575,373	245,989	6,603,470
France	0.27	11	14	279,353	1,829,659	42,207	131,920
Germany	0.27	11	17	278,886	710,265	11,912	454,800
Belgium	0.27	11	14	458,403	507,475	13,561	30,504
Comparison with Brazil							
USA/Brazil		4.25	3.5	471.19%	185.49%	151.06%	110.72%
France/Brazil		2.75	3.5	271.83%	32.09%	25.92%	2.21%
Germany/Brazil		2.75	4.25	271.38%	12.46%	7.32%	7.63%
Belgium/Brazil		2.75	3.5	446.06%	8.90%	8.33%	0.51%

*Calculated from **Table A1** results.*

health sector that it is less about health resource endowments but more about the efficiency of using the available resources. The study also showed that, without pharmaceutical interventions like vaccines, the prevailing healthcare resources and NPIs used in combating major pandemics like COVID-19 appear to help fewer countries. Therefore, the healthcare sector should invest more in proactive than reactive management of pandemics, for example, through continuous research and development on preventative medication. The study is constrained in several ways. The DEA results are heavily dependent on the selection of analytical variables. Therefore, a different set of indicators may lead to a different collection of results. The credibility and accuracy of statistics used also affect the results of the models—data of the pandemic is getting more refined over time. This study adds to the literature on modeling the efficient use of resources in world healthcare systems with the inclusion of undesirable outputs. The methodology that we developed can, at any time, be replicated as new data becomes available as the pandemic progresses or when new pandemics develop.

DATA AVAILABILITY STATEMENT

The original contributions presented in the study are included in the article/supplementary material, further inquiries can be directed to the corresponding author/s.

AUTHOR CONTRIBUTIONS

All authors listed have made a substantial, direct and intellectual contribution to the work, and approved it for publication.

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Conflict of Interest: The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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APPENDIX

TABLE A1 | Analytical variables and efficiency scores.

Studied units		Model I				Model II				Model III			
DMU #	**Country**	**CRS efficiency score**	**VRS efficiency score**	**Scale**	**Type of scale**	**CRS efficiency score**	**VRS efficiency score**	**Scale**	**Type of scale**	**CRS efficiency score**	**VRS efficiency score**	**Scale**	**Type of scale**
1	USA	0.12	0.18	0.67	IRS	0.07	0.18	0.39	IRS	0.29	0.33	0.89	DRS
2	India	0.33	0.33	1.00	–	0.38	0.39	0.96	DRS	1.00	1.00	1.00	–
3	Brazil	0.83	1.00	0.83	DRS	0.40	0.75	0.54	IRS	1.00	1.00	1.00	–
4	Russia	0.47	0.60	0.78	IRS	0.37	0.60	0.62	IRS	0.18	0.64	0.29	IRS
5	France	0.03	0.27	0.11	IRS	0.01	0.27	0.04	IRS	0.01	0.27	0.03	IRS
6	Spain	0.22	0.33	0.67	IRS	0.11	0.33	0.33	IRS	0.07	0.34	0.19	IRS
7	Argentina	0.33	0.33	1.00	–	0.16	0.33	0.48	IRS	0.16	0.36	0.46	IRS
8	UK	0.20	0.30	0.67	IRS	0.07	0.30	0.22	IRS	0.05	0.31	0.17	IRS
9	Columbia	0.43	0.43	1.00	DRS	0.22	0.43	0.50	IRS	0.16	0.45	0.34	IRS
10	Italy	0.15	0.33	0.44	IRS	0.04	0.33	0.13	IRS	0.03	0.33	0.08	IRS
11	Mexico	0.67	0.77	0.87	IRS	0.11	0.77	0.14	IRS	0.40	0.95	0.42	IRS
12	Peru	0.60	0.60	1.00	–	0.21	0.60	0.35	IRS	0.15	0.62	0.24	IRS
13	South Africa	0.50	0.50	1.00	–	0.30	0.50	0.61	IRS	0.13	0.54	0.24	IRS
14	Iran	0.26	0.33	0.78	IRS	0.07	0.33	0.22	IRS	0.09	0.34	0.27	IRS
15	Germany	0.18	0.27	0.67	IRS	0.15	0.27	0.55	IRS	0.03	0.27	0.10	IRS
16	Poland	0.17	0.38	0.45	IRS	0.15	0.38	0.41	IRS	0.03	0.38	0.07	IRS
17	Chile	0.67	1.00	0.67	DRS	0.30	0.60	0.49	IRS	0.09	0.61	0.15	IRS
18	Iraq	0.60	0.60	1.00	–	0.37	0.60	0.62	IRS	0.09	0.60	0.15	IRS
19	Belgium	0.03	0.27	0.11	IRS	0.01	0.27	0.03	IRS	0.00	0.27	0.01	IRS
20	Ukraine	0.24	0.43	0.55	IRS	0.16	0.43	0.36	IRS	0.03	0.43	0.07	IRS
21	Indonesia	0.95	1.00	0.95	IRS	0.44	1.00	0.44	IRS	0.23	1.00	0.23	IRS
22	Czechia	0.29	0.43	0.67	IRS	0.32	0.43	0.75	IRS	0.03	0.43	0.06	IRS
23	Bangladesh	1.00	1.00	1.00	–	1.00	1.00	1.00	–	0.43	1.00	0.43	IRS
24	Netherlands	0.18	0.27	0.67	IRS	0.13	0.27	0.46	IRS	0.02	0.27	0.07	IRS
25	Philippines	0.60	0.60	1.00	–	0.46	0.60	0.77	IRS	0.08	0.60	0.14	IRS
26	Turkey	0.60	0.60	1.00	–	0.27	0.60	0.45	IRS	0.05	0.60	0.09	IRS
27	Saudi Arabia	0.42	0.70	0.60	DRS	0.33	0.40	0.83	IRS	0.04	0.38	0.10	IRS
28	Pakistan	1.00	1.00	1.00	–	0.82	1.00	0.82	IRS	0.16	1.00	0.16	IRS
29	Romania	0.47	0.60	0.78	IRS	0.23	0.60	0.38	IRS	0.03	0.60	0.05	IRS
30	Israel	0.42	0.50	0.83	DRS	0.63	0.65	0.97	IRS	0.03	0.38	0.07	IRS
31	Canada	0.27	0.30	0.89	IRS	0.09	0.30	0.30	IRS	0.02	0.30	0.05	IRS
32	Morocco	0.89	1.00	0.89	IRS	0.88	1.00	0.88	IRS	0.02	1.00	0.02	IRS
33	Switzerland	0.19	0.33	0.56	IRS	0.19	0.33	0.58	IRS	0.01	0.33	0.03	IRS
34	Nepal	0.44	0.50	0.89	IRS	1.00	1.00	1.00	–	0.03	0.50	0.07	IRS
35	Portugal	0.20	0.30	0.67	IRS	0.16	0.30	0.52	IRS	0.01	0.30	0.02	IRS
36	Ecuador	0.52	0.66	0.79	DRS	0.10	0.46	0.21	IRS	0.05	0.46	0.11	IRS
Mean		0.43	0.53	0.76		0.30	0.52	0.51		0.14	0.53	0.22	
# of efficient DMUs		2	6	10		2	5	2		2	6	2	

Based on data envelopment analysis efficiency calculated results.

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Rethinking the Epidemiogenic Power of Modern Western Societies

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Keywords: COVID-19, industrialized societies, epidemic, public health, non-pharmacological measures

INTRODUCTION

In less than a year, COVID-19 has imposed itself as one of the major health crises in the history of Western democracies although, as zoonotic diseases go, it is not especially deadly, nor are its symptoms especially terrifying (Harvard Health, 2020; Ioannidis, 2020). Faced with the spread of COVID-19, one of the most noticeable reactions of governments have been to impose lock-downs and important restrictions on freedom of movement and of association. These radical decisions caused such severe negative externalities (unemployment, poverty, inequality, loneliness, anxiety, depression, violence and the loss of schooling for millions of children) that they can only be temporary (Altman, 2020; Arpino et al., 2020; Banks, Karjalainen, and Propper 2020; Benke et al., 2020; Bonaccorsi et al., 2020; Czymara 2020; Green 2020; Grover et al., 2020; Martin et al., 2020; Usher et al., 2020; Fountoulakis et al., 2021). Such unparalleled restraints in peace-time were explicitly conceived as temporary measures to control, or mitigate, the spread of the epidemic while waiting for an effective and safe vaccine to be developed (See for instance Stella Kyriakides, EU commissioner for health and food safety, declaration on April 2020 Day, 2020). Even softer measures, such as social distancing and mask-wearing, were seen as ancillary to the main weapon—vaccination—and the assumption was that they had no relevance to healthcare in "normal" times.

Thanks to an unpreceded pharmacological effort, the development and roll-out of a variety of safe, effective vaccines against COVID 19 has occurred, offering concrete means to end this crisis (Zimmer et al., 2020). Nonetheless, these pharmacological solutions should not prevent the consideration of those factors, endogenous to our societies, which helped to catalize this pandemic. Indeed, this paper argues, epidemics reflect a combination of exogenous and endogenous factors. Attention only to the former risks underestimating what we call 'the epidemicogenic' dimensions of our society, at the risk of leaving us yet more vulnerable to destructive epidemics in future.

ISSUES WITH PHARMACOLOGICAL SOLUTIONS

The European Commission and the World Health Organization have both emphasized the importance of ensuring that pharmacological tools against Covid-19 are developed collaboratively and made accessible to all equally, in order to counter the medical, political and social risks of the pandemic (Riordan, 2020; World Health Organization 2020). They fear, rightly, that otherwise scientific developments on which everyone depends will be instrumentalized by those who are able to monopolise them, and used to advance sectarian political, economic or ideological agendas. Within countries, not merely internationally, differential access to healthcare can be used to favor one social groups over others, and to discriminate on racial, religious and ethnic grounds (as it has already been the case for food distribution (The New Humanitarian, 2002) and the international context makes such problems possible, if not probable. In July, already, Putin announced the

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development of a safe vaccine against COVID-19 by Russia (Official website vaccine against coronavirus Sputnik V, 2020). This announcement places Russia as a leader in technological development with all its potential consequences, including the military ones. The name of the vaccine itself, Sputnik V, reveals the reputational, diplomatic and political intentions behind the announcement.

Besides these political and ethical considerations, the long-term consequences of relying on pharmacological solutions for epidemics are not promising; scientists have indicated that pandemics may be more and more frequent in the future, due to the erosion of natural habitats exacerbated by global warming, agricultural intensification and urban areas extension (Dasgupta and Andersen 2020; Epstein, 2000; International, 2020; Madhav et al., 2017). Specifically, by causing an average temperature rise and increasing contact between humans, livestock and wildlife, these practices create the ideal conditions for the development and spread of zoonotic diseases. However, vaccines, in their nature, are disease-specific, and thus an inefficient way of protecting global public health. Successful vaccines for global health threats of any severity and scale require the dedication of colossal disease-specific resources, as we have seen, with the real possibility of extensive restrictions on civil liberty in the meantime. Considerable emphasis has been put on the economic and mental health consequences of the COVID-19 pandemic, but little attention until now has been paid to the consequences of mass deaths for families and the generational balance among populations, although as know from the HIV epidemic in Africa, these can be severe. Moreover, the psychological effects of acute exposure to the risk of infectious disease have significant political and social consequences in themselves. Epidemics tend to produce xenophobic scapegoating and hostility to 'outsiders' (Clissold et al., 2020; Schaller, 2011; White, 2020)—in this case, Asian communities in the West have borne the brunt of that hostility since Spring 2020. Such empirically observable tendencies appear also in experimental psychology research, which shows that real or perceived exposure to a threatening pathogen increases racist and xenophobic attitudes in test participants (Aarøe et al, 2017; Faulkner et al., 2004; Millar, Fink-Armold, and Lovitt 2020). So instead of looking for made to measure, post-hoc, solutions to each large-scale epidemic, it is crucial to find ways to prevent them and, where that is impossible, to minimize their severity.

DISEASES AS EXTERNAL ENEMIES: THE EXOGENOUS DIALECTIC

Mainstream political discourse presents epidemics as an external enemy and epidemic prevention as a process of repelling this external threat. Emmanuel Macron's reference to wartime, in his speech announcing the France's lockdown in March 2020 exemplified the phenomenon (Macron, 2020). The representation of epidemics as something external fits naturally with intuitive Western images of disease as an alien threat to the body. Pathogens worm their way into the population and cause an epidemic in just the same way that they insinuate themselves into individual bodies and cause disease (Napier, 2020). Although widely shared in Western societies, this view is far from universal. For example, the Balinese view of immunity is based more on the idea that humans play an active role in the circulation of viruses than on the idea that they are external threats to the self (Napier, 2020). Importantly, the exogenous representation adopted by Westerners faces two problems. First, it ignores the fact that acute infections often give rise to chronic illness and, even when cured, can damage one's ability to fight further infections in future some illnesses, can leave one vulnerable to new infections over the long term, as well as to the chronic illness over a life time which acute infections often entail, (e.g. Bonaccorsi et al., 2020; Musher, Abers, and Corrales-Medina 2019; Sejvar, 2007; Xiong et al., 2020). In the case of COVID-19, specifically, an increasing number of incapacitating long-term pathologies have been noted by the medical community, and it is quite possible that the full range of long-term damage from COVID 19 has not yet been appreciated (Carfì, Bernabei, and Bermpohl; CDC 2020; Fraser, 2020). However, the second main problem with the idea that disease, and particularly epidemics, can be adequately conceptualized as an external threat to an otherwise healthy body/society is that this ignores the social conditions that make epidemics possible, and which help to determine who will suffer most from them.

The exponential spread of COVID-19 in Western countries, therefore, forces us to consider the causal role of our structuring institutions, habits and norms in turning what might have been a relatively contained disease into an epidemic that had hit us full force by March 2020. Indeed, in Autumn as in Spring 2020, most Western countries experienced exponential rises in the number of COVID-19 cases (Roser et al., 2020). Thus even if this particular epidemic emerged from China, and was made worse by the persecution of journalists and doctors there, (e.g. Waterson, 2021), Western societies have clearly played a role in its propagation and development–in part, through their reluctance to accept that the epidemic could be controlled without access to a vaccine, as seems largely to have happened in South East Asia (An and Tang 2020). As Ludovic et al. (2020) have highlighted, integration into a globalized market economy has been one of the drivers of the COVID-19 pandemic. Indeed, countries with higher levels of trade also experienced a higher number of COVID-19 cases in april 2020. While the increased circulation of people between countries is undoubtedly a factor in this association, the question arises as to whether this effect has not also been mediated by the very structure of modern Western societies.

THE STRUCTURE OF WESTERN MODERN SOCIETIES AS EPIDEMIC ACCELERATORS

Significant outbreaks of Covid-19 in slaughterhouses throughout Europe (Académie nationale de) have reminded us of the importance of healthy working and living conditions in containing lethal epidemics, such as *tuberculosis*, diptheria, and measles long before there was a vaccine for them, or, as in the case of cholera, in controlling diseases for which there is no

vaccine (Porter, 2005). Slaughterhouses are poorly ventilated and crowded workplaces and their employees often share cramped, unsanitary housing conditions as well. Whereas the importance of adequate ventilation has only recently been stressed as an essential tool in controlling the spread of COVID-19 (Connolly, 2020), its importance to the control of *tuberculosis* was known since the late 19th century (Dubos and Dubos, 1987). More recently, the importance of fresh air and sanitary conditions to the health of non-human animals was highlighted by the role of intensive livestock farming in the spread of zoonotic diseases. Intensive poultry farms suffer more from the development of coccidiosis, a potential fatal disease for chickens, due to the over-crowding of animals (Tewari and Maharana 2011), and "mad cow disease""—less colloquially known as Bovine Spongiform Encephalopathy—is thought to have arisen as a result of feeding intensively farmed cattle with meat-and-bone- meal (Colchester and Colchester 2005). Its human form, Creutzfeldt-Jakob disease is thought to have been transmitted by eating contaminated cattle. In short, the importance of fresh air, low density housing, safe drinking water, food safety and effective waste collection were all key to the control of epidemics before the advent of modern treatments for them. However, it seems that repeated zoonotic epidemics are necessary to remind us of their continuing relevance nowadays.

A critical look at the organization of many industrialized societies highlights the contrast between classic public health measures, and current ways of living in our societies, with their high population density, constant population movements and life, work and travel in low ventilation indoor areas. Even in hospitals and doctors' offices fresh air can be hard to come by, and in the United States, notoriously, one is not supposed to open windows because centralized heating and air conditioning mean that this otherwise innocent gesture risks over-heating or freezing hapless co-workers elsewhere in the building.

Moreover, the social organization of contemporary industrialized societies appears at odds with the primary principles of public health. While "case isolation" has been one of the central elements of the strategy of the World Health Organization for managing COVID-19 epidemic, this principle cannot be implemented given the current constraints on workplace organization. In addition to the statutory and economic constraints on sick leave, such as the existence of unpaid days during paid sick leave, Western societies, create a moral and reputational incentive to work, even when feeling unwell, because of the importance that they attach to being "productive." Moreover, health insurance for cattle and crops, as well as for people, are generally available only at significant personal cost, although if widely used they would promote an important public good: the rapid sharing of reliable information about infections before they become epidemics. As such, industrialized societies unite the material and psychological characteristics that spread disease. This social organization is at odds with the natural behavior individuals adopt when threatened with disease. Psychological studies in experimental settings show that individuals tend to avoid contact with potentially infectious individuals (Schaller and Park 2011; Park, Van Leeuwen, and Chochorelou 2013; Blacker and LoBue 2016). Such individually and collectively beneficial behavior, unfortunately, is hard to adopt in societies where people are forced to work in close contact with others, and to commute using overcrowded public transport.

UNDERSTANDING THE ROOTS OF THE EPIDEMIOGENIC POWER OF WESTERN SOCIETIES

However, if the factors that contribute to epidemics are well-known and, in a sense, part of folk knowledge, we can wonder why industrialized societies are designed the way they are. The rise of a productivity and growth-centered economy since the Second World War is an important factor. Two other factors also strike us as essential to current vulnerabilities to epidemics, though so far, they have not received attention. The first, is the compartimentalization of society, such that problems of human health are largely separated from the health of non-human animals, pollution and the design of our physical and social environment. Not only does this make it difficult to recognize changes in public health which are relevant to epidemics, as in the case of pollution (Fattorini and Regoli 2020; Frontera et al., 2020; Travaglio et al., 2021), but it makes it harder to integrate knowledge across public policy areas.

Second, with the successful development of vaccines and antibiotics since the Second World War, diseases such as diptheria, measles, *tuberculosis*, polio have become distant threats for many of us, rather than omnipresent threats to families and, especially, to their most vulnerable members. vulnerable members. Although the 21st century is not exempt from life-threatening transmissible diseases, in most industrialized countries these mainly concern specific "at-risk" populations rather than everyone: older people for the seasonal flu, LGBT communities and drug addicts for AIDS, prisoners and deprived urban populations for *tuberculosis*. In other words, mass infectious diseases have become less and less of a concern for public policies in most countries, and outbreaks are publicly treated as isolated and exceptional events. In this context, public health principles are increasingly ignored in the development of contemporary societies, paving the path for the exponential spread of epidemics.

CONCLUSION

In this paper, we highlight the structural, epidemiogenic factors in industrialized societies that contribute to the development, intensification and spread of epidemics. While these factors are generally acknowledged when dealing with epidemics in non-human species, their significance for humans was only slowly recognized in the early stages of the COVID-19 pandemic. Reconsidering the structural factors that place our societies on a collision course with the most basic lessons of public health is the only way to design long-term solutions to current epidemics, and to prevent further ones in future. Recognizing and changing those factors is, also, the only way to combat the socially

inegalitarian patterns of risk and illness, which COVID-19 has laid bare (Wolff and de-Shalit, 2007; Wilkinson and Kate, 2009). Crowded, unsanitary housing; poorly ventilated and dilapidated schools; poorly paid work, with no entitlement to sick leave or parental leave, means that the burdens of COVID-19 fall hardest on socially vulnerable groups who, too often, are the offspring of parents and grandparents who, themselves, suffered discrimination, exploitation and neglect (Patel et al., 2020). In short, recognizing and correcting the endogenous determinants of epidemics is not simply a matter of prudence, or of wise public policy. It is also a matter of justice, and of our duty for future generations.

AUTHOR CONTRIBUTIONS

AL and LS equally contributed to the conception and the redaction of the manuscript.

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Global Agri-Food Sector: Challenges and Opportunities in COVID-19 Pandemic

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COVID-19 pandemic has been catastrophic for almost everything including the global economy. Among many sectors, the food and the agriculture sector was the worst hit following the immediate lockdown and market shutdowns. Though some stability was prevalent from supply side till date, however, the severe restrictions put in place to curb the spread of pandemic have endangered the supply of agricultural and food articles contemporaneously across borders and from field to fork. While the income decline due to price falland supplies chain disruptions due to pandemic have escalated the food shortages in several of developing and developed countries. Nevertheless the global demand for food items has remained more or less unchanged owing to their inelastic demand. Even within the global level, the scenario of food security and supply chain stability has been substantially deplorable for emerging and less developing countries due to their lack of insulation to the global shocks or pandemics. Notably, the technological backwardness, excessive know-how dependence and denied accessibility on several grounds lead to poverty and food hunger in these countries. At the policy level, a holistic approach specifically targeted towards the developing and less developed economies is highly warranted to ensure an appreciable progress towards the minimisation of sensitivity with regard to agriculture and food security. Apart from the measures to insulate them from global shocks, additional steps need to be taken to alleviate their technological backwardness and denied accessibility on certain socio-cultural norms.

Keywords: global pandemics, agricultural commodities, world economy, routine demands, under developed nations, food security

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INTRODUCTION

SARS-nCoV-2 is a novel virus known to cause COVID-19 disease which is responsible to 1.6 million deaths in six continents of the globe as World Health Organization (WHO) declared state of health emergency on March 11, 2020 due to this pandemic disease and so far global total of cases 71.6 million are confirmed till date (WHO, 2020a; Hamid et al., 2020). WHO (2020a) issued Strategic preparedness and response plan to implement the measures regarding community participation, temporary travel restrictions, social gatherings, closure of educational institutes and work places. Work from home recommended for various sectors but it cannot be applied to food sector that needs to work in their daily routine. With regards to the economy, the food industry is a very significant field which is life sustaining than the rest of sectors like as tourism and aviation after a pandemic, the food industry faces various sets of problems. The pandemic could lead to an aviation loss of US$113

billion and a tourism industry loss of US$80 billion (IATA, 2020; FAO and WHO, 2020). Preserving the welfare of the employee and having enough staff instead of those who do not choose to work because of pandemic remained big concern shared by all food corporations. In order to keep food chain alive it was mandatory for the management to supply and distribute food and to work on continuous manner during pandemics. With the contribution of all parties, the management of the distribution of food and services across the supply chain should be assured. Ensuring customer interest is also important for food quality and protection (UNTWO). At this moment of crisis, food sustainability is related to the proximity of customers to food rather than access to food (OECD, 2020d). No study reveals that COVID-19 has to date been spread through food intake, in view of the large size of the pandemic. However in Xinfandi market, new infections have been seen due to processing of salmon fishes which can be inferred that the risk of the virus that spread by foods is lower than the perceived risk. SARS-CoV-2 can be dangerous source of food borne transmission while taking consideration of its survival in a number of environments, such as rubber, steel or cardboard, animal tissue (meat, fish or poultry). Food business operators' hygiene controls are intended to avoid food contamination by any pathogen and would also aim to prevent food contamination by the COVID-19 virus (European Commission, 2020a; FAO, 2020b). Any cooking and eating habits, however may contribute to the reappearance of corona virus from animals to humans (Pressman et al., 2020).

Effects of Pandemic on Food Supply Chain

Agricultural production, postharvest handling, processing, distribution/retail/service, and consumption i.e., field to fork are the 5 phases of Food supply chain (FSC). In the food supply chain, two mechanisms surrounding food consistency and protection are used. The first is focused on rules and legislation that use compulsory requirements that are reviewed by state departments. The second is focused on voluntary principles established by business laws or international organisations (Rizou et al., 2020). According to Rizou et al., (Pressman et al., 2020), FSC involves critical last stages where people can get infected easily, hence for the safe handling/preparation/delivery of food, using personal protective equipments such as helmets and glove, sanitization of surfaces and working environments, even the maintenance of social distance are some Safety measures to ensure the continuity of food flow. The COVID-19 pandemic does not specifically impact development, unlike foot and mouth disease, bird flu or Listeria, since it does not propagate directly to animals or agricultural products (Richards and Rickard, 2020). However as a result of the pandemic, policymakers around the world have placed major limits on the flow of goods (land, sea and air transport) as well as on labor mobility. Reports have indicated that the use of food delivery vehicles has reduced to 60% after the constraints in France were 30% before the pandemic (IATA, 2020; OECD, 2020c). Temporary or seasonal sort of employment is common in developing and underdeveloped countries, particularly when planting, sorting, harvesting, refining, or transporting crops to markets. Therefore, due to the lack of local or temporary workers due to illness or travel restrictions enforced by the lockdown, the supply chain is greatly impacted. In situations where the illness specifically impacts their health or activity, it also weakens not only the processing ability of others but also their own food protection (ILO, 2020a). The lack of labor due to the pandemic crisis has led to significant disturbances in certain industries, such as livestock production, horticulture, planting, harvesting and crop processing, which are relatively labor intensive. Farm worker shortages, however, were already a significant concern long before the COVID-19 epidemic (ILO, 2020b). The "Pick for Britain" campaign in Britain was planned to locate 70,000 British working in the field and through the harvest (Deng et al., 2015). However, owing to the lack of labor due to sickness and the physical distance to be sustained during production, the crisis is weakening the opportunity to work for farms and agricultural undertakings. These conditions delayed the delivery of grain and agricultural inputs and produced difficulties with the continued supply of food to markets (Author Anonymous, 2020b).

Effects of Pandemic on Global Food Trade

While the current circumstances appear unprecedented, even before the COVID-19 crisis, food supplies were vulnerable to climate-related and disease-related issues. Food markets have historically been fragile due to numerous incidents and shocks, such as the oil crisis in the 1970s, the outbreaks of SARS and Ebola, and the food crisis from 2006 to 2008. Only a year ago, Africa's Swine Fever outbreak upset the world commodity markets and became a progressive epidemic in Eastern Europe and Asia. By the end of 2019, China, the world's biggest pig manufacturer (1/3 of the global market) and largest exporter had lost 37% of its pigs (IPES, 2020). In certain African countries, the production, marketing, and trade economies regarding agriculture where Ebola created huge damages. The ongoing COVID-19 crisis has modified certain governments' food trading policies, aimed at limiting exports and making imports simpler. Ensuring the preservation of the number of goods in the domestic market is the key reason why countries implement export restrictions. Although this outcome is usually produced by an export limitation in the short term, it still has some negative consequences. Ban on export resulted domestic price drop due to which farmers economy got hit *via* low crop production and decreased incentives in the industry. As well as export controls lead to a reduction in domestic markets, triggering a financial downturn to producers and reducing business incentives. Secondly, by losing their position on foreign markets, countries would lose their economic edge. The third explanation is that export controls damage the image of the exporter and allow importers to decrease confidence in the global markets, thus reducing foreign trading trust and undermining potential export business prospects (Espitia et al., 2020).

Impact on Food Production and Distribution

In order to monitor the rate of infection, most nations have taken steps such as home confinement, travel restrictions and business closure. Such regulations have a huge effect on the food delivery at any point of the food supply chain. It is estimated that world trade

in goods will decrease from COVID-19 by 13–22% (FAO, 2005). Different areas of agriculture have received serious pandemics, such as wheat, livestock and fisheries. With inadequate access to animal feed and a lack of work, (WTO, 2020), COVID-19 in China has had a greater effect in livestock production. Travel ban has limited the availability of reproductive supplies of poultry in many countries. Prolonged restrictions on travel vanished the breeding stock and hatching eggs as per reports of The International Poultry Council (IPC) (Zhang, 2020). As we know the cheap source of protein for 3 million people thus accounting more than 20% of animal protein for the human consumption (Vorotnikov, 2020). In various parts of Asia, Africa and Europe, aquaculture suffered huge losses due to labor shortage, inadequate input supplies when the other main causes were social distance and lack of feed (FAO, 2020e). Farmers are required to store their unsold produce for a longer period of time, which leads to a decrease in food quality as well as a rise in production costs (FAO, 2020e). COVID-19 has been struck worst by the supply of milk and dairy products. After a substantial decline in milk production and the closing of the milk manufacturing business, dairy farmers are forced to dump milk and milk products. Dairy producers in America report that nearly 4 million gallons of milk were spilled every day by farmers nationwide (Forstadt, 2020). In Nepal, 2 billion NPR dairy products have been destroyed and 5 billion NPR dairy products in storage tend to be on the edge of deterioration (NepaliSansar, 2020). Since the Great Recession of 1929 to current pandemic of covd-19, world is suffering from huge loss in terms of economy, social and psychological which set the countries on worst crizes according to International Monetary Fund (Marlow, 2020) among the past epidemics including the 2002–2003 SARS (Severe Acute Respiratory Syndrome) epidemic; the 2003 North American BSE (Bovine Spongiform Encephalopathy) crisis and the 2003–2004H5N1 avian influenza epidemic. Compared to 2019, a 4.9% decline in global Gross domestic product (GDP) has been projected for 2020; the European Union (10.2%, with peaks for Italy and Spain, both 12.8%, and France, 12.5%), the United Kingdom (10.2%), Canada (8.4%), and the United States are among the most significant economies experiencing losses (8.0%). In spite of the fact that the corona virus is extremely infectious and that an antidote is not yet available on the market, the forced shutdown of industrial and business operations has created chaos in the entire economic sector (Cucinotta and Vanelli, 2020). The pandemic will shock the supply and demand sides of market demand, many economists say. The former applies to interruptions in the provision of goods and services, while the latter refers to the volume of consumption and procurement of products (OECD, 2020a). Standard food supply chain (FSC) functions are impeded by COVID-19 including farmers, manufacturing plants, wholesalers, and retailers (ILO, 2020a) form a diverse FSC. Breakdowns or bottlenecks in some section of the FSC have impacted other components up and down the chain during the current COVID-19 pandemic. The findings of recent analyses have shown that the shock in the supply of labor has undergone the largest decrease (OECD, 2020a; Johnso and Mue lle, 2002), leading to instability of the supply chain and dumping or waste of foodstuffs at fields. This instability is due to the absence of grain harvesting, the aggregation of farm goods, and the interruption of the distribution network (Cucinotta and Vanelli, 2020). The shelves of grocery stores (supermarkets) were often vacant as a result of this FSC disturbance (a lack of workforce in packaging and selling goods to retailers), which was also attributed to hoarding and panic buying, which in turn contributed to the scarcity of essential foodstuffs (NepaliSansar, 2020). Many policymakers have reduced the selling and export of foodstuffs and boosted imports of essential products (CDC, 2020a) to avoid such a shortage. The lack of supply in retail stores and the growing demand from households have had a substantial effect on the volatility of agricultural product prices (Cucinotta and Vanelli, 2020). In the meantime, a massive demand shock has been reported in the hotel, restaurant, and catering (Ho.Re.Ca.) sectors, with a big effect on the food system (CDC, 2020b; WHO. HIV/AIDS, 2020). The global pandemic expansion has and will continue to have an unparalleled detrimental effect on households and firms' existing and future livelihoods. Consumer conduct, as a buying decision mechanism, is a behavioral process, as described by Engel et al. (Lopez-Ridaura et al., 2019), which is observed before and after purchase. The action of consumers is very dynamic, requiring a wide variety of activities, from intake to disposal (Zavatta, 2014). Several influences including global, geographic, social and demographic diversity, as well as consumer tastes and attitudes, which are all of feed intake (World Bank, 2019).

Agro-Food Consumption Habits and Preferences

Since the FSC and food supply were affected by the economic crisis and the occurrence of the COVID-19 pandemic, many have resolved this deviation from normality by changing their food preference reactions and behavior. Bree (2020) has indicated that forming a new habit typically takes approximately 3 weeks to develop. Clearly, the COVID-19 crisis lasted well longer than 3 weeks, but what began as a transition in customer behavior has now become a habit. According to the EY Future Consumer Index by Rogers and Cosgrove (2020), 28% of cautiously lavish consumers (25% of the 4,859 consumers surveyed in the United States, Canada, the United Kingdom, France and Germany during the week beginning April 6, 2020) will change their eating habits as they change their eating habits, according to the EY Future Consumer Index by Rogers and Cosgrove (Hubbub, 2020) of the five consumer segments to take on prominence as the COVID-19 crisis can be said to have ended. Since after lockdown implementation from 16th March 2020 in United Kingdom changed the cooking and eating behavior among 90% of a representative sample of 2,000 adults surveyed as per research conducted by Hubbub (Datassential, 2020). People remained indoors and spend long hours to prepare meals while enjoying cooking at home (44%); and "sharing" virtual meals over Zoom, Skype, Facetime etc., (40%) and with neighbors (47%). Such recently discovered dietary patterns include better menu preparation, the use of cupboard staples, the freezing of food/meals and the increased use of leftovers. As

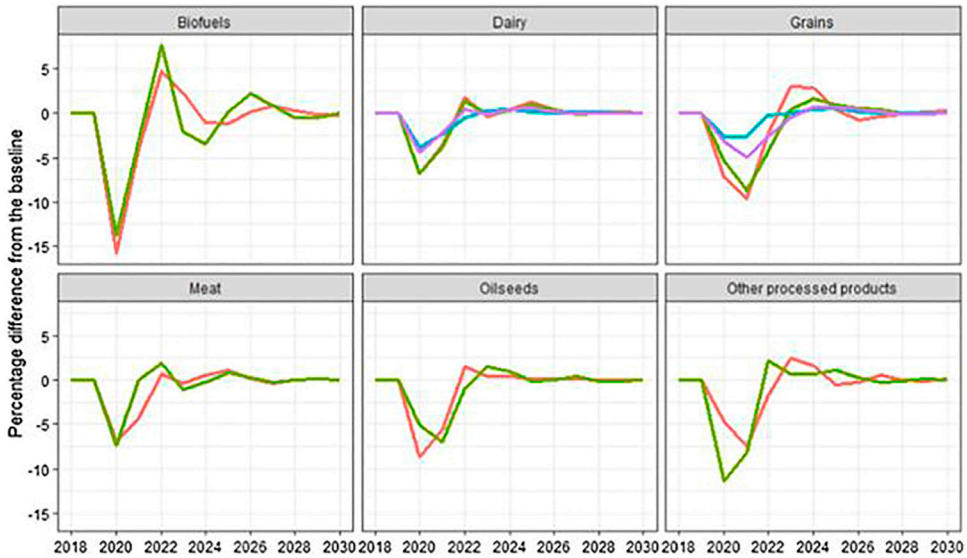

FIGURE 1 | Impacts on world prices on the basis of Percentage difference from the baseline [Source: Elleby et al. (2020)].

TABLE 1 | Shows the estimated impacts on global food prices until 2025 on comparison with GDP baseline shocks.

Items	2020	2021	2022	2023	2024	2025	Band (%)
Biodiesel	−15.9	−4.0	4.7	2.3	−1.0	−1.2	22.4
Butter	−6.8	−3.6	−1.7	−0.3	0.4	1.3	4.6
Skim milk powder	−3.8	−2.4	−0.4	0.3	0.5	0.2	0.9
Rice	−2.7	−2.7	−0.3	0.0	0.4	0.5	2.7
Wheat	−3.2	−4.9	−2.6	−0.4	0.7	0.7	3.9
Beef and veal	−10.4	−0.5	6.9	−1.5	−3.0	0.9	1.8
Vegetable oils	−11.4	−8.1	2.2	0.7	0.7	1.1	6.6
Poultry	−7.0	−4.2	0.7	−0.3	0.5	1.1	3.2
Pork	−17.6	4.7	7.2	−4.3	−0.8	2.9	3.7
Total protein meal	−4.7	−7.5	−1.7	2.5	1.6	−0.5	4.5

per research conducted by Hubbub (Allen, 2004) also found that many individuals did not eat as much fresh fruit and vegetables as normal (31%), reducing their interaction with shops, while some also decreased their milk/egg consumption throughout the lockdown era (15%) (**Figure 1**). Shortages and challenges in obtaining staple food ingredients caused many to attempt new recipes (22%). Finally, there are signs that these emerging habits will persist after the limits have been greatly removed, albeit to a lesser degree (**Table 1**) (Elleby et al., 2020).

Global GDP and Pandemics

However, uncertainty remained as to how long the COVID-19 recession will last and what the medium-term global economic effects will be. It relies on many factors, including agricultural commodities that affect the supply and demand. These include how fast multinational companies will resort to lock-outs; whether secondary waves will cause policymakers to implement new lock-down measures; how quickly the SARS-CoV-2 virus can be vaccinated and/or successful treated, and how any of it affects market habits. However the COVID-19 effect on their GDP estimates already represents a variety of global economic outlooks. The projections for the global GDP reduction in 2020 by the IMF, World Bank and OECD range from 3.0 to 7.5% and the forecasts for the resulting global GDP rise in 2021 range from 2.8 to 58%. (IMF, 2020; World Bank, 2020a). The International Food Policy Research Institute (IFPRI) forecasts that the economic downturn in 2020 will increase the number of people living in severe poverty by a whopping 20% or 140 million people, resulting in expanded food insecurity in many countries, building on the IMF projection (Laborde et al., 2020). In countries dependent on seasonal migrant workers in the agro-food industry, a sudden loss of mobility across borders and within countries has triggered labor shortages, which in turn has impacted food supply and prices globally (Hernandez et al., 2020). For example, the prices of some main staples in India and in several African countries have reportedly risen by more than 15% from pre-COVID-19 levels (OECD, 2015). The pandemic has also influenced trade in goods by, for example additional border controls, lack of shipments of freight and improved sanitary controls. In addition, the pandemic, analogous to the food crisis of 2007–2008, caused several countries to enact export bans in order to protect their domestic customers (Author Anonymous, 2020a). These trade frictions may impact global food prices as well. The Organization for Economic Co-operation and Development (OECD) Secretariat and the Food and Agriculture Organization of the United Nations (FAO) developed recursive-dynamic partial equilibrium model namely Aglink-Cosimo which is an outcome of their collaboration (Araujo-Enciso et al., 2015; EC., 2019). In order to project the baseline for the main agricultural commodities over the medium term, this modeling approach has been used to produce the OECD-FAO and EU Medium Term Agricultural Outlooks (FAO., 2020f). A single scenario, augmented by EU from the spring 2020 Economic Prediction by the European Commission, is evaluated based on

country-specific GDP growth projections in the IMF, World Economic Outlook database (April 2020). The scenario shocks are the GDP growth rates expected by the 2020 and 2021, the GDP base line and the 2021 scenario. We believe the GDPs come back to their core principles from 2022 and beyond.

Global Impacts

A stochastic theoretical study has been conducted on the relationship between foreign oil prices and the agricultural product markets in addition to the scenario impacts, expressed as a range of point's forecasts. The agriculture and energy sectors are interlinked primarily through the output of bio-fuels (mainly mandated) and the cost of input (e.g., fertiliser costs). At present, due to a mixture of supply and demand factors, we are facing a time of low oil prices. As discussed below, however, foreign oil prices in the model are exogenous and we have not made any conclusions regarding their divergence from the baseline to retain a strict emphasis on the impact of COVID-19 on production. Instead, based on the historical volatility of oil prices, we calculate the joint distribution of scenario effects, where the variation derives from alternate oil price projections. A declining trend has been observed for the prices of vegetable oils, meats and bio-fuels as well as same trend were found for agricultural commodities in 2020. On comparison with baseline data, the prices will be underneath in 2021 for some lamb and pork flesh. The illustration is more mixed for 2020, with the grains and bio-fuels above and below the baseline. All product prices are near and close to baseline values as we come to 2025. Until the end of the 2030 prediction era, this will continue to happen. Mainly through production of bio-fuels (managed to a significant degree) and input prices, agricultural and energy markets interconnect (e.g., fertiliser costs). At present, due to combined supply and demand considerations, we are faced with a time of low price. Trade ties international economies with the global economy. As a result, a rise in inflation on the global economy is generally often responsible for an increase in internal prices.

Recommendations to Minimize the Effect of Covid-19

The outbreak of the COVID-19 severely endangers food security, nutrition and welfare. The financial chaos caused by the pandemic risks the access to food economically and physically accessible. Disrupted marketing, logistics and commercial networks, and potential problems could limit access to food in some parts of the world (FAO, 2020c). World Food Program study has indicated that by 2020, COVID-19 will increase the number of individuals suffering serious poverty to 265 million (WFP, 2020a). Another research undertaken by Headey et al. (WTF, 2020a) found that COVID-19 contributes to a rise of 14.3% in the incidence of lack of health and social security for low or middle-income children under the age of 5 years of age.

Actions on Global Trade

It is important to continue the movement of agricultural inputs between countries, even in the case of quarantine restrictions or the closure of borders. Acts should also be taken in the short term to encourage trade in agricultural inputs such as machinery and fertilisers, as these needs are essential for the smooth continuity of planting activities (Headey et al., 2020). Trade and tax practises need to be discussed to keep free trade open. At the beginning of the COVID-19 epidemic, some of the big exporting countries adopted the "beggar thy neighbor" approach that requires importer countries to cover the costs or dangers of insufficient supply. The distributional consequences of "beggar thy neighbor" often include food price spikes and a reduction in food security (FAO, 2020d). Countries should also lift export prohibitions and import taxes because the food prices can be avoided by lowering import tariffs due to low food supply (Headey et al., 2020). As a result, the protectionism of food trading included various types of taxes, tariffs, non-tariff barriers and restrictions (Barichello, 2020). However the introduction of these policies has led to a disparity between demand and supply, contributing, in the medium and long term, to a sharp increase in global food prices. Therefore the most disadvantaged group of the remaining players in the supply chain is the economically marginalized clients.

Sociological Theories for Food Security

At the end of the Cold War and a shaky global surge in democracy, a flood of new information technologies that bring the global community closer together and contribute to the rapid expansion of globalization, the explosion of a global HIV/AIDS pandemic, and a 35% increase in the world's population have all been witnessed by the world. Simultaneously, there are constants like violence and war, widespread poverty and inequality, and ongoing environmental challenges. Hunger persists in all of this, and sociology's role in solving it requires further and more attention. As per the reports of FAO, (Food and Agriculture Organization of the United Nations, 2008), and (FAO, 2021), Less developed Nations are the hotspot which comprises of nearly 96% of the world's total hunger population as these 82 nations have been categorized "low-income food deficit" countries with chronically poor, net importers of food and are prone to diseases including covid-19 while the Hotspot for hunger lies in Sub-Saharan Africa and South and Southeast Asia. Children under age five, who include the huge mass of the world's food insecure, encompass 18,000 of the 25,000 people per day who die of hunger, adding together more than 6.5 million per year [U.N. (World Food Programme)]. Food insecurity is defined by shortages, poverty, and suffering, according to DeRose et al., (1998). Food insecurity is most directly connected to inequality, with a focus on distribution and variables that affect food access. When people are unable "to secure sufficient food to satisfy the nutritional needs of their family members owing to insufficient income, limited access to productive resources, inability to benefit from private or governmental food transfers, or lack of other entitlements to food," they are said to be in food poverty (Uvin and Yverdon, 1994). The present global food crisis due to covid-19 pandemic is a good illustration of how food insecurity may have far-reaching consequences particularly for the poor but also for people who appear to be food secure such as those in the middle class who feel the sting of rising food prices. Food sovereignty, according to McMichael (2004), is "a

community's or country's social right to set its own policies surrounding food security (enough supply and acceptable cuisine) and the cultural, social, and ecological circumstances under which it is sustained" (Menezes, 2001). Food insecurity is as much a function of political economics and the global economic system as it is of population and technology. Food insecurity's persistence underscores its worldwide relevance (Devereux, 2007). Unlike previous crizes, globalization has fostered interdependency, where issues in one part of the world influence difficulties in another. This is the setting that necessitates a new social understanding of food security/insecurity. As a result of globalization, governments have shifted from feeding themselves to exporting cash crops to the rest of the world. Buying food for consumption in the "global food order" and becoming net food importers on the market (Friedmann, 1982). In order to compete with global agri-business, local markets and prices are disrupted, and peasants who grow crops for local use are evicted off their land. Ironically, many of the people who create the world's food supplies are hungry themselves (Barkin, 1982; McMichael, 1995). In India, a shortage of labor, storage, or transportation choices resulted in losses for 40% of farmers who faced a production drop in April 2020. Small and marginal farmers made up around 52% of the respondents, landless farmers made up 6.7%, medium farmers made up 19.9%, and large farmers made up 20.7%. Over half of the farmers claimed harvesting cost more this season than the previous season, either to a lack of labor or machinery, or a greater cost of machinery. Food security/insecurity is political in terms of its ties to social movements and social transformation, in addition to macro-structural, global political economy processes. Food and hunger-related collective action has a wide range of applications including food riots (McMichael, 2004) and food justice movements (Walton and David, 1994) in addition to sustainability (Allen, 2004; Wekerle, 2004), cooperative (Buttel, 1997), food sovereignty (David and Michael, 2004), and local/slow foods movements (Petrini and Gigi, 2006; Schnell, 2007). The freegan subculture, which gleans food that has been thrown away, including dumpster diving as a political act, draws attention to food waste and global consumption patterns by gleaning food that has been thrown away (Edwards and Mercer, 2007). When many people go hungry, freegans fight the unfairness of overconsumption and inequity. The act of eating may plainly be political, and sociology of power, politics, and social movements has a long history of helping to grasp its importance for global food security and insecurity. Food insecurity is linked to a variety of factors, including class, ethnicity, and gender as well as development, land availability, rural-urban inequities, and age. Food insecurity is mostly caused by a lack of financial resources to purchase food. The poor are the hardest hit among these persons, resulting in a situation in which the country performs significantly worse than its contemporaries in the industrialized world. This is especially true in light of the present economic slump, which has resulted in the formation of new and spreading "food deserts" in the United States, where people are either jobless or going hungry for the first time in their lives. According to Poppendieck (1995), insecurity of food generates a scenario of "heat or eat". People forgo eating for rent, services or medical charges. In addition to the substantial US welfare reform in 1996, the importance of stratification for food insecurity becomes even more apparent, combining poverty with gender and ethnic discrimination. Moreover, despite their role in all stages of food production, distribution, and processing, food insecurity among women and girls in the globe continues to be pervasive. Extending this to racial disparity worldwide demonstrates how lamination systems pose as obstacles to food distribution and other fundamental necessities. Among other locations, state failures in Eritrea, Ethiopia, Indonesia, Somalia, Sri Lanka, and Sudan (Messer et al., 1998) demonstrate the plague of ethnic disparity for food security. Food security and insecurity addressing are crucial to international peacekeeping and security efforts in conflict areas (Bryant and Christina, 2005). Food security is a crucial component of how stable, sustainable societies are created with the strong links to poverty and underdevelopment.

Applicability of Theory of Access to Food Security

As defined by the theory of Access distinguishes between one's right to access resources and one's ability to profit from them. People may have the right to access a resource, but due to a lack of structural and relational mechanisms such as capital, technology, labor, knowledge, authority, market mechanisms, social relations, and identity they may not be able to use the resource in a productive way to benefit from it (Ribot and Peluso, 2003). It has also been highlighted by Uvin (Devereux, 2007) that food insecurity includes numerous components. According to McKay and Colque (2016), accessing resources requires procedures that go beyond legal norms or titles, and that a lack of such processes leads to exclusion. Suppose a farmer could have the right to utilize the land but not the labor or cash to rent it. The most significant resource for agricultural productivity for smallholder farmers is land, followed by irrigation water. Water used for irrigation aids agricultural crop development and mitigates the impacts of insufficient rainfall. Access to productive resources may assist small farmers, through improving production and adapting to and mitigating the climatic changes, to implement sustainable land management measures, such as water conservation measures and nutrient management. Food security is one of the prerequisites or outcomes of a livelihood. Smallholder farmers are subject to food insecurity and have unsustainable livelihoods due to a lack of access to productive resources. The majority of population in the least Developed nations including India, Somalia, Kenya, Pakistan and other countries whose livelihood depends on Agriculture and livestock production. In order to check the wide applicability of Theory of Access, a small study has been carried out in north-western slopes of Mount Kenya, covering parts of Laikipia and Meru countries, as this theory holds broader significance while considering different variables (Swindale and Bilinsky, 2006). For households which depend on agricultural and livestock production for their livelihoods, access to production resources, such as land and water is essential. Research generally assumes that the tenure of resource security (expressed as a "bundle of property rights") is favourable for agricultural output, and consequently food security.

However in the category of bundle of rights and powers, following variables which form state of art include Access to Right, technology, Markets, knowledge, labor and labor opportunities, capital, Access through social identity and through social relationships, Rights-based access to irrigation water. Household Dietary Diversity Score (World Food programme, 2008), Food Consumption Score (Maxwell and Caldwell, 2008), Coping Strategy Index (Coates et al., 2007), Household Food Insecurity Access Scale (Bilinsky and Swindale, 2010), and Months of Inadequate Food Provisioning (Mutea et al., 2020) were used to estimate the food security status of the tested homes. Mutea and co-workers in 2020 assessed in their study whether each family is satisfied with the food security requirements for each of the five indicators to get a sense of their overall food security situation. In order to categorize safe and insecure food, Mutea et al. (World Food Programme, 2020a) utilized the food safety thresholds for the respective indices. Household food security via the lens of the Theory of Access has an application that has yet to be fully explored for industrialized countries in order to determine the optimal relation for each variable. The majority of the farmers in this research had property rights to their agricultural resources and were able to profit from them. Instead, it indicated that the fundamental issue was a lack of access to the technology required to unlock additional advantages from households' productive resources, leaving these households exposed to food insecurity. Hence, greater number of variables can be included even can compared for the Least developed Nations in order to frame the components which are lacking or have put the poor families or farmers livelihood into halt as making them prone to hunger and food security and also this theory can be used for comparative analysis in order to determine changing variables foe all the countries which comes under the category of food insecurity.

Statistical Analysis Over 45 Developing Nations for Food Security

By the end of 2020, the number for acute hunger will double as per findings of United Nations World Food Program (WFP) (Food and Agriculture Organization of the United Nations et al., 2020). The pandemic COVID-19 will result in addition of 83–132 million people into the category of malnutrition by 2020 according to estimates of Food and Agriculture Organization (World Trade Organization, 2020). While adapting measures to abate transmission rates, The World Trade Organization (WTO) (Food and Agriculture Organization of the United Nations) reported that countries like Egypt, Thailand, North Macedonia, Ukraine and Kyrgyzstan started ban over certain food and agricultural products. Some countries which are largest suppliers of wheat like Russia, Rice like Vietnam implemented export-restrictions while majority of countries put forth custom restriction *via* cargo export as pandemic has escalated the tensions between the United States and China, in which food exchange taris have been used as an instrument of economic pressure intensively (Erokhin and Gao, 2020).

Erokhin and Gao (World Bank, 2020b) tried to understand the relation between food security, food trade, dynamics of COVID-19 cases, currency volatilities and food inflation by dividing the 45 developing nations into three group studies in order to carry out statistical analysis using Yamamoto's causality test, variance decomposition, autoregressive distributed lag method on the basis of level of income. With a gross national income (GNI) per capita of $1,025 equal or less according to norms of World Bank (Puma et al., 2015) have kept under Group I likewise GNI per capita between $1,026 and $3,995 comprises Group II countries and GNI per capita between $3,996 and $12,375 includes Group III. This study pertains to check the dynamicity among different variables which were included as

1. Y = Number of people with insufficient food consumption (Unit-millions of people),
2. X1 = Number of confirmed COVID-19 cases (Unit-Number of cases),
3. X2 = Balance of food trade (USD million),
4. X3 = Food inflation (Percentage) and
5. X4 = Currency exchange (Unit-Monetary units)

Their study explains the cumulative effects of covid-19 pandemic on overall food security in 45 developing nation by including variables X (Hamid et al., 2020; IATA, 2020; FAO and WHO, 2020) as per trends of Hunger map of WFP. The food trade balance (X2) represented the country's reliance on imports of food and thus revealed improvements in the availability of food. Food inflation (X3) and currency exchange (X4) have been used to demonstrate the effect on food security of changes in access to food and agricultural products (**Figure 2**). It has been observed that in countries like Ecuador, Pakistan, India, Turkey and Peru (primarily middle-income economies) where the number of reported COVID-19 cases per capita is high, the Y-X1 linkage showed significant results. Lower developing countries are dependent on import for the staple crops as both global food chain disruptions and protectionist trade policies lead to great economic losses could have serious negative consequences for food security [Puma (Wood et al., 2018) and Wood et al. (Frankenberg et al., 2019)].

After evaluating the results of various hypothesis testing, Erokhin and Tianming Gao (Smith and Glauber, 2020) put forth that across Group I, number of people with insufficient food consumption (Y) is unidirectional linked to food trade balance (X2) but the significance of the link is low even in the countries like Tajikistan, Haiti and Guinea where food availability largely depends on imports. For import-dependent upper-middle-income economies, the greatest influence of X2 on Y is seen to be in countries like Algeria, Botswana, Colombia, Jordan, Lebanon. In most low-income nations, a lower proportion of food imports in exchange is correlated with a decline in the percentage of people with inadequate food intake. However, findings of this study concluded that Group I and Group II economies depend on imports less diversified than Group III countries that are more tightly integrated into global supply chains. In the latter situation, greater reliance on imports means that the Food Trade Balance, currency exchange, and therefore the food security position of the people are more affected. In North Africa and the Middle East countries that relies on imports of food and therefore rely on

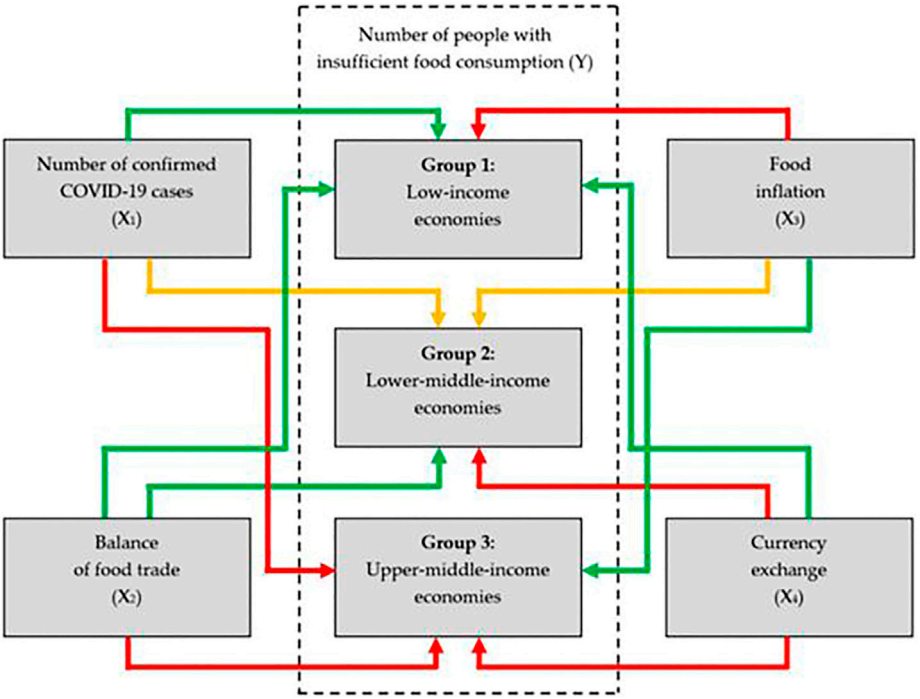

FIGURE 2 | Summary of X (FAO and WHO, 2020; Hamid et al., 2020; IATA, 2020; WHO, 2020a) effects on Y across three groups of countries where Green showing weak influence; yellow shows medium influence and Red showing strong influence (Source: Erokhin and Gao (McMichael, 2004).

currency fluctuations induced by the pandemic, UNCTAD [95] revealed increased risks for food safety. The best results of X2 and X4 on Y on Algeria and Turkey are seen in favor of this UNCTAD prediction. In another Hypothesis there is an anticipation trend of an increase in the share Y of food trade as well as exchanges in currency, particularly in the countries with the highest middle income. The most significant influence of X2 on Y is expected in Libya, where reliance on food imports exceeds 90% (18.03%). The X2 in Y proportion is almost 12% in March 2021 in Namibia, which is another Category III nation primarily dependent on imports. In countries closely embedded in the global food supply chains, the role of the currency exchange in securing food supply would increase. In Turkey, for example, X4 describes 15.21% of Y. In contrast with those in low income countries, the effect of food inflation on the number of people with inadequate food intake in high-middle income economies has been lower. This result confirms Hypothesis 3 (the effects of X4 and X2 on Y are the highest among the economies included in the study, while that of X3 is the lowest) coincides both with Frankenberg and Thomas (Giordani et al., 2014) and Smith and Glauber (Anderson and Nelgen, 2012) who announce that elevated food price rates have exacerbated poor households' poverty traps, but have no major impact on the relatively good food safety status. For example, in Cambodia we saw the limited exports of some agricultural produce between March–April 2020, which resulted in the reduction in the number of people with insuccinating food intake, both negative balances of trade in food and low inflation in foodstuffs. Vietnam and Turkey, on the other hand, have not been very active in their decisions to reduce food exports. The ARDL study indicates that a 1% shift in the food trade balance is correlated with a 0.02% rise in food poverty in Vietnam. The X2-Y partnership is poorer but still optimistic in Turkey. This study showed major causal association between X3 and Y in both countries (5%! 0.35% in Turkey and 5%! 0.31% in Vietnam). This finding confirms the estimates of Anderson and Nelgen (Rude and An, 2015), Giordani et al. (Dawe and Peter Timmer, 2012), and Rude and An [68], who found that trade protectionism could cause food inflation and thus intensify food insecurity.

CONCLUSION

In the current situation, the global issue is food quality and safety. COVID-19, which provides food coverage for the most vulnerable section of the population at risk, has struck the supply chain the hardest. In general food demand is very inelastic and it takes many years for supply to completely respond to a shift in prices, so the shocks in GDP have only a marginal effect on global production and consumption. The inability to contain the COVID-19 pandemic has had far-reaching consequences for the world economy, with global GDP expected to plummet by 3.3% by 2020. Despite the fact that the global economy is expected to increase by 6% in 2021, recovery will be contingent on fair vaccine distribution worldwide. According to the International Chamber of Commerce, failure to do so might cost the global economy up to $9 trillion, with losses shared evenly by rich and poor countries, wreaking greater economic havoc than the 2008 financial crisis.

High value added goods such as meat and milk as well as bio-fuels are the commodities whose production changes the most. In order to ensure the welfare of farm workers, countries should take action. Healthcare workers on staff should monitor employees' disease status. Countries can create collection centres for agricultural production at locations easily reached by small-scale farmers to minimize mobility. Collection centres for agricultural production should be built to provide high capacity storage for (Beghin, 2014; FAO, 2020a). In order to reduce the depletion of food throughout the food supply chain, enhanced and specialized storage systems should also be used. However when additional capital injection is needed new facilities or improved technology include higher manufacturing costs. Small and medium-sized agricultural firms may also maintain their operations through government or donor capital injections (Anang et al., 2015; World Food Programme, 2020b). Food banks may play a significant role in considering the horizontal and vertical cooperation structures with farmer associations that allow pledged agriculture procedure. Developing countries will suffer the most despite any economic or food crisis mainly because of their limited resources and are subjected to the deterioration of the macroeconomic environment. It is interesting to note that before the pandemic over 2 billion of the most impoverished people in the world spent 70% of their disposable income on food so this reiterates the importance of food security and how a disruption in the supply chain can have serious repercussions on more than a quarter of the world's population. Unless immediate action is taken, the number of people experiencing acute food insecurity is expected to double to 265 million by 2020, as per the World Food Programme (2020b). However, even in Developed nations, more vulnerable groups such as the elderly, chronically ill, and poorer households may be at danger, and COVID-19 has exposed pre-existing social protection deficiencies (OECD, 2020b). Future comparative sociological research on food safety can be built on recent research which has established sociological positions on this arena. It is traditionally dominated by research that overly concerns production and supply and is not sufficiently concerned with the conflicts, stratification and inequality most essential to starvation. The European Union's Farm to Fork Strategy described food system conversion system to focus on future resilience, health and sustainability. Their issued statement regarding framework were focused on that there can be environmental, health and social benefits, economic gains and ensuring that a resurgence from the crisis can lead us to the sustainable route (European Commission, 2020b).

AUTHOR CONTRIBUTIONS

All authors listed have made a substantial, direct, and intellectual contribution to the work and approved it for publication.

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Compilation and Application of the Scale of Sustainable Knowledge Sharing Willingness in Virtual Academic Community During the Times of the Coronavirus Pandemic (COVID-19)

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With the outbreak of COVID-19, many offline academic activities have been turned online, and virtual academic communities have been further emphasized. Based on this situation, this study took the Eagly and Chaiken's Heuristic-System Model of Persuasion and the general rules of behavioral decision as a theoretical basis, established a theoretical model of sustainable knowledge sharing willingness in virtual academic communities. Firstly, this study developed the scale of willingness to share sustainable knowledge based on the heuristic system model of persuasion. After analyzing the data of 62 participants, the scale was revised. Secondly, 256 valid data were collected from China, the United States, Singapore, and Indonesia. Finally, the conceptual model and theoretical hypothesis were tested based on the data. The results show that knowledge sharing satisfaction is affected by heuristic factors (knowledge sharing quantity, knowledge source credibility) and system factors (knowledge sharing quality, knowledge sharing usefulness), and has a significant positive correlation with sustainable knowledge sharing willingness.

Keywords: Heuristic-System Model, academic virtual community, COVID-19, sustainable knowledge sharing, willingness

INTRODUCTION

With the rapid development of modern information technology and the popularization and application of the Internet, new digital scientific research environments such as E-Learning are increasingly formed and mature. Especially under the influence of current COVID-19, new knowledge sharing mode with an virtual academic community as the carrier has emerged and received extensive attention (Castaneda and Cuellar, 2020). The virtual academic community will gather researchers with common or similar research interests together to release questions, discuss questions, provide answers and share knowledge around the same topic, to realize knowledge

sharing (Marquez et al., 2016). The virtual academic community has broken through the time, space, and discipline restrictions changed the knowledge production mode based on disciplines and documents, complied with the needs of real-time scientific research, interactive scientific research, open scientific research, and collaborative scientific research in the network era, which become an important platform for researchers to share knowledge (Cantor, 2019).

In recent years, with the rapid development of virtual academic community, the scale of community users such as Academia, ResearchGATE, Mendeley, etc. has been expanding, which not only allows users to share and view the latest scientific research results in time but also helps users to establish community relations, to make academic exchanges more smooth and knowledge sharing more efficient. But at the same time, there are also some academic virtual communities with low user participation, less knowledge sharing activities, and users' sustainable use intention declining. The establishment soon began to decline, which did not achieve the purpose of academic exchange. From the perspective of knowledge management, virtual academic community constructs a new paradigm of knowledge production, storage, sharing, and utilization, which provides the resources, technology, and environment needed for knowledge sharing, while knowledge sharing provides power and guarantee for the sustainable development of the virtual academic community (Cheng et al., 2018). Therefore, the sustainable participation of users in knowledge sharing is the key to the success of the virtual academic community (Chandran and Alammari, 2020). In this paper, the Heuristic-Systematic Model of Persuasion (HSMPP) (Chaiken et al., 1989) and the general rules of human behavior decision-making are used to construct a heuristic for sustainable knowledge sharing in virtual academic community and the scale was formed. The systematic model explores the influence of heuristic variables and systematic variables on the willingness of sustainable knowledge sharing and analyzes the obstacles and countermeasures of sustainable knowledge sharing in virtual academic community.

LITERATURE REVIEW

Sustainable Knowledge Sharing in Virtual Academic Community

The sustainable development of virtual academic community depends on whether users are willing to share knowledge sustainably. The main challenge is that knowledge in the virtual academic community is non-competitive and non-exclusive, which is usually regarded as "public goods" (Rice et al., 2018). Cabrera and Cabrera (2002) believed that all people in an organization, whether they have contributed knowledge or not, can obtain shared resources, and the use of knowledge resources by each person will not reduce the use of these resources by others (Cabrera and Cabrera, 2002). The public goods attribute of knowledge tends to lead to the imbalance of sharing. People are always willing to obtain and use free knowledge resources, rather than contribute their own knowledge, which leads to "free-riding" behavior. However, according to Simon's "limited rationality" theory, everyone is limited rationality, and community members may share knowledge because of irrational factors such as interpersonal relationships and emotion (Cristofaro, 2017). Therefore, there are many factors influencing knowledge sharing and sustainable willingness.

At present, the research mainly focuses on the endogenous factors such as emotional factors, psychological cognition, individual motivation, or the external variables such as technical function, social impact, situational environment to study the sustainable willingness in knowledge sharing of virtual academic community. Ranjbarfard and Sureshjani (2018) constructed a framework for knowledge sharing in virtual academic community between teachers and students, and studied the role of partnership requirements, collaborative learning services, and social networks on the willingness to sustainable knowledge sharing (Ranjbarfard and Sureshjani, 2018). Cheung and Lee (2007) pointed out that internal motivation has a strong correlation with knowledge self-efficacy, which has a significant positive impact on the willingness to continue knowledge sharing (Cheung and Lee, 2007). Chiu et al. (2011) constructed a model based on expectation recognition theory and fairness theory, pointed out that the uncertainty of self-worth, fairness of distribution, and fairness of interaction significantly affect the satisfaction and willingness of members of virtual community (Chiu et al., 2011). The existing researches have made fruitful results by using the inherent model of classical theory, but they have not distinguished the heuristic behavior and systematic behavior of knowledge sharing, and have not yet studied the rational and irrational factors and their mechanism of knowledge sharing behavior.

Application of HSMP

The HSMP is a dual processing theoretical model proposed by psychologist Chaiken to explain the process of individual information behavior (Chaiken et al., 1989). Chaiken believed that human social activities have two kinds of information processing modes: heuristic and systematic (Chaiken et al., 1989). The heuristic behavior based on intuition means that people pay less cognitive effort and make a simple judgment according to the external clues of information (Chaiken, 1980). For example, the implication of source credibility may trigger the rule that trust means right, making people more willing to accept information sent by people with high trust. Systematic behavior based on rationality means that people use enough cognitive resources to systematically evaluate relevant information content (Chaiken, 1980). Users' evaluation of information quality mainly considers the information content itself (such as discussion quality and discussion intensity), not only the non-content factors such as information source reliability and information quantity.

HSMP provides an in-depth theoretical explanation for how individuals deal with information, evaluate information, use information, and form decision-making in different situations, which is widely used to explore the influencing factors and situational conditions of heuristic and systematic information behavior (Chandran and Alammari, 2020). Wirth et al. (2007) proposed that information search behavior can be divided into heuristic and systematic patterns, and the importance of search

experience and search results is the main factor to distinguish the two behavior patterns (Wirth et al., 2007). Lucassen et al. (2011) pointed out that for Wikipedia, students with a high degree of trust tend to adopt heuristic information behavior mode, and pay more attention to the quantity of information. On the contrary, they tend to adopt systematic information behavior mode and pay more attention to the quality of information (Lucassen et al., 2011). Zhang et al. (2014) believed that consumers' acceptance of online comment information is a dual process, including heuristic and systematic behaviors, information source reliability and comment quantity cognition are heuristic variables, comment quality is systematic variables, and both variables have a significant impact on consumers' behavior attitude (Zhang et al., 2014).

At present, there are little researches on knowledge sharing using HSMP. Compared with the technology acceptance model and user satisfaction model, the advantages of HSMP lie in that the model is not a fixed theoretical model composed of several specific variables, but a general framework and behavior paradigm of behavior decision-making research, which has a strong theoretical expansion and explanatory power. Using HSMP to study the sustainable knowledge sharing of virtual academic community can identify the key influencing factors and mechanism of knowledge sharing satisfaction and sustainable willingness from the general rule of behavior decision-making, without the limitation of intrinsic variables and their relations.

RESEARCH MODEL AND HYPOTHESIS

Hypotheses in Satisfaction Model

Satisfaction refers to the recognition degree of users for products, services, and behavior processes, including the evaluation after adoption and the feeling state formed in the use process (Changchit and Klaus, 2020). Satisfaction has a stable positive correlation with the user's intention to continue to use, which can predict the user's intention to continue to use (Bae, 2017). For the virtual academic community, user satisfaction is the premise of its sustainable development. If the user is not satisfied, it will reduce community activities and even cancel the account (Borcsa and Pomini, 2017). Therefore, in the virtual academic community, the satisfaction of knowledge sharing has a positive impact on sustainable willingness, and the relationship between them is as follows:

- H1: there is a positive correlation between satisfaction of knowledge sharing and sustainable knowledge sharing willingness in virtual academic community.

Relevant Hypotheses of HSMP

Knowledge sharing behavior in virtual academic community is a complex dual process and has two kinds of behaviors: heuristic and systematic, which are affected, respectively. The direct measurement of heuristic and systematic cues is to see the amount of information processed and the degree of fine processing, which is difficult to operate. Some scholars try to use indirect measurement to explore two kinds of clues, that is, to investigate people's processing methods of information content characteristics and external characteristics. Zhang et al. (2014) regarded the quantity perception and source credibility of online reviews as clues of heuristic behavior, and the cognition and discussion intensity of information degree as clues of systematic behavior to study the impact of online reviews on online shopping (Zhang et al., 2014). The behavior pattern regards the top of the page as a heuristic behavior and the middle position as the system behavior according to the location where the user clicks on the search page (Kim et al., 2014; Ghoses et al., 2018).

Because the HSMP does not put forward specific criteria for dividing heuristic and systematic behaviors, the academic community has not formed a unified view on the measurement scale of the two behaviors (Schemer et al., 2008). According to the research of Chaiken (1980), explicit factors such as external cues of behavior and formal characteristics of information are regarded as heuristic variables, potential factors such as central cues of behavior and internal characteristics of information are regarded as systematic variables, and reliability and quality are the most important influencing factors of initiating and systematic behaviors, respectively (Chaiken, 1980). In the process of knowledge sharing in virtual academic community, knowledge quality and usefulness judgment need more cognitive resources to analyze the content and value of knowledge sharing, so it can be used as the influencing factor of systematic behavior. The judgment of knowledge quantity and credibility is relatively simple thinking of external available clues, which consumes relatively less cognitive resources, and can be used as an influencing factor of heuristic behavior.

Relevant Hypotheses of Systematic Variables

The quality and usefulness of knowledge sharing are two main indicators to measure the level of knowledge sharing, which reflect the value of knowledge sharing among members of virtual academic community. Many studies show that quality, usefulness, and satisfaction of knowledge sharing are related. Bouncken and Aslam (2019) pointed out that the higher the quality of shared knowledge, the more expected it is, the higher the user satisfaction (Bouncken and Aslam, 2019). Gang and Ravichandran (2015) pointed out that usefulness is an important factor affecting community satisfaction (Gang and Ravichandran, 2015). Therefore, if the virtual academic community can provide users with timely and highly relevant knowledge to discuss topics, and increase users' useful awareness of knowledge sharing, then users' satisfaction with the knowledge sharing process will be improved. Based on this, this paper proposes the following assumptions:

- H2: there is a positive correlation between quality and satisfaction of knowledge sharing in virtual academic community.
- H3: there is a positive correlation between the usefulness and satisfaction of knowledge sharing in virtual academic community.

Related Hypotheses of Heuristic Variables

The credibility of knowledge source refers to the users' overall perception of the credibility of knowledge source, including the

reliability and professionalism of knowledge source, in which the reliability is related to the familiarity of community members to knowledge contributors and the recognition of knowledge. Professionalism is related to the professional experience, academic influence, and social identity of knowledge contributors in relevant fields. When people adopt heuristic behavior, they usually regard source credibility as the main basis for decision-making and judgment, and think that "expert opinion is correct" and "expert means authority and reliability" (Bonner et al., 2006). Boratto et al. (2016) showed that persuasive information with high source reliability can stimulate users' positive evaluation (Boratto et al., 2016). Therefore, this paper holds that there is the following relationship between the credibility of knowledge source and the satisfaction of knowledge sharing in virtual academic community:

- H4: there is a positive correlation between the credibility of knowledge source and satisfaction of virtual academic community.

Quantity of knowledge sharing is another important heuristic clue, which plays an important role in user satisfaction evaluation (Altman et al., 2018). This paper studies the numbers of knowledge sharing from four aspects: total knowledge, the information contained, update frequency, and several participants. When people take heuristic evaluation to the satisfaction of knowledge sharing, they often judge the significant characteristics and external performance of knowledge sharing simply according to experience and intuition. Many studies also use quantity as a heuristic variable. Chaiken (1980) took the amount of information and the preferences of information recipients as the influencing factors of the evaluation of the information reception effect (Chaiken, 1980). Gao et al. (2012) found that the more the amount of reference information, the more conducive to reducing the differences in users' expectations of products and improving users' satisfaction (Gao et al., 2012). Accordingly, the following assumptions are proposed:

- H5: there is a positive correlation between the quantity of knowledge sharing and satisfaction of virtual academic community.

Hypotheses Between Heuristic Variables and Systematic Variables

According to the HSMP, heuristic behavior and systematic behavior can occur at the same time, and the two behaviors interact with each other, resulting in a certain deviation in the final behavior. Specifically, if the two behavior results are similar, user behavior has the characteristics of both heuristic and systematic behavior patterns. The behavior results are intuitive and rational, and the two behaviors have an additive effect. If the results of the two behaviors are different, they need to further investigate the specific situation. If the situation information is clear and the conditions are clear, then the systematic behavior has a weakening effect on the heuristic behavior. People tend to adopt the system behavior based on rational judgment, otherwise, the heuristic behavior is dominant, people tend to adopt the heuristic behavior based on intuitive judgment, and produce irrational deviation.

In the process of satisfaction evaluation and decision-making of knowledge sharing in virtual academic community, the credibility of knowledge source and quantity of knowledge sharing can stimulate users' cognition of the usefulness of knowledge and actively infer the sharing results. Chinn and Rinehart pointed out that the credibility of knowledge sources has an important impact on perceived usefulness (Chinn and Rinehart, 2016). When it is difficult for community members to judge the value of subject knowledge, if the credibility of these knowledge sources is high, and the amount of knowledge shared is large, then the members are likely to think that knowledge is of high usefulness. Therefore, this paper proposes the following assumptions:

- H6: there is a positive correlation between the credibility of knowledge source and perceived usefulness in virtual academic community.
- H7: there is a positive correlation between the quantity of knowledge sharing and perceived usefulness in virtual academic community.

Relevant Hypotheses of Social Impact Variables

Virtual academic community is a social organization based on a network. Knowledge sharing among community members is a social exchange activity. Its process and results are affected by social capital factors. According to the theory of social exchange, people follow the principle of interest exchange in the process of knowledge sharing, exchange other people's knowledge by contributing knowledge or expect similar help in the future, to achieve mutual benefit (Park et al., 2015). The expectation based on mutual benefit represents the invisible norm of "mutual debt," which can be understood as a strong sense of fairness coexisting in giving and acquiring. Only when knowledge contribution is rewarded, can community members effectively stimulate their willingness to continuously contribute their knowledge? Ganguly et al. (2019) showed that reciprocity has an important impact on the quality and quantity of knowledge sharing, and knowledge-collectors must return equal or more knowledge to their contributors to maintain knowledge exchange activities (Ganguly et al., 2019). As an important relational social capital, reciprocity can help people realize the potential value of knowledge sharing, and promote knowledge exchange and knowledge sharing by improving people's understanding and satisfaction of their potential needs. The stronger the reciprocal belief of members of virtual academic community, the more willing they are to participate in knowledge acquisition and exchange activities, and the more willing they are to share more high-quality knowledge with others. Therefore, this paper holds that reciprocity has the following relations with the quantity and quality of knowledge sharing:

- H8: there is a positive correlation between the reciprocity among members of virtual academic community and the quantity of knowledge sharing.

- H9: there is a positive correlation between the reciprocity among members of virtual academic community and the quality of knowledge sharing.

In social organizations, social connection is an important content of social capital structure, and also an important channel for information exchange and knowledge acquisition, representing the strength of a two-way relationship between members. Close social connection means stability, trust, and cooperation, which can promote members' understanding of the overall objectives and behaviors of the organization, stimulate members' efforts, and reduce concerns about the effectiveness of knowledge sharing, to ensure the transfer and sharing of high-quality knowledge. Many studies have confirmed the important influence of social contact on information exchange and knowledge sharing. Research on the evaluation of social e-commerce word-of-mouth indicates that social contact can effectively promote user communication, which has a significant impact on the quantity and quality of online word-of-mouth (Goraya et al., 2019). Hall and Merolla (2020) measured social connection from three aspects: communication frequency, time, and closeness, which showed that social connection can stimulate the external motivation of community members and improve the quality of knowledge sharing (Hall and Merolla, 2020). In the virtual academic community, the closely related community members are willing to share more knowledge and higher quality. Accordingly, the following assumptions are proposed:

- H10: there is a positive correlation between the social connection and the quantity of knowledge sharing among members of virtual academic community.
- H11: there is a positive correlation between the social connection among members of virtual academic community and the quality of knowledge sharing.

Based on the above assumptions, this study proposes the following research model, as shown in **Figure 1**.

MATERIALS AND METHODS

Selection of Experimental Platform

This study mainly choose ResearchGATE and Mendeley to collect experimental data, see **Figure 2**. ResearchGate is a professional network composed of scientists and researchers. At present, more than 20 million members from all over the world have used it to share, discover and discuss research. Its main functions are to update research consultation at any time, communicate with researchers in professional fields in time, and provide sustainable learning approaches. At the same time, the platform is free to open research to all people, and has strict privacy protection technology and service aims to ensure the safety of data and shared knowledge. Mendeley is a free reference manager and sharing platform, which has been used by more than one million users. Its main function is to help store, organize, record, share, and quote reference materials and research data. The main advantage of Mendeley is that it can easily collaborate with other researchers online, obtain literature and share opinions from multiple sources. Based on the above introduction of the two platforms, it can be known that both platforms are open to the outside world free of charge and have a large number of users, which is convenient for later sample selection and data collection. At the same time, these two platforms are the international mainstream academic virtual community platforms, which have been recognized by researchers, so it is representative to choose these two platforms.

Sample Selection

Firstly, during the COVID-19 period, this paper collected 500 demographic information from China (including Taiwan Province and Hong Kong), the United States, Singapore and Indonesia by using the virtual academic community platform. All participants were informed of the purpose of this study and the confidentiality of data at the beginning, and once they filled out the questionnaire of this study, they agreed to participate. Secondly, this study randomly selected 100 people to conduct pre-survey with self-designed scale (see **Table A1**), its main purpose is to test whether there is any language expression or unclear meaning in the questionnaire. A total of 62 valid questionnaires were collected in the pre-survey, and the researchers adjusted them according to the feedback results of the pre-survey. Finally, because 100 people have been filled out and interviewed in the pre-survey study, in order to ensure the reliability and accuracy of the data, this study excluded these participants in the formal survey, and the remaining 400 people were formally investigated in this study, and 256 valid questionnaires were recovered. In terms of gender, 62% of the respondents were male and 38% were female. In terms of professional titles, professors account for 21%, associate professors account for 32%, and lecturers and graduate students account for 47%; As far as age structure is concerned, 82% are aged 29–45, 8% are over 45, and 10% are under 29. In terms of subject background, the natural sciences accounted for 64%, and the social sciences and humanities accounted for 36%. The study was conducted by the Declaration of Helsinki (2002) and Measures for Ethical Review of Biomedical Research Involving Humans, Ministry of Health, China. The protocol was approved by the Ethics Committee of Nanjing Normal University.

Procedure

In order to better discuss and measure the knowledge sharing willingness of researchers in virtual academic community, this study conducted a cross-sectional survey of 500 researchers from February 2020 to June 2020. The main experimental design includes four parts: firstly, getting the scale factor structure and research hypothesis according to the results of HSMP and literature review. Secondly, 100 researchers were selected for pre-survey and interview to ensure the accuracy of the scale. Thirdly, the remaining 400 researchers were finally filled out with questionnaires and collected with data. Finally, SPSS and Amos are used to analyze the data and draw a conclusion. It is worth mentioning that the reason why this study adopts online survey is that it is difficult for researchers to collect data face to face due to the outbreak of epidemic.

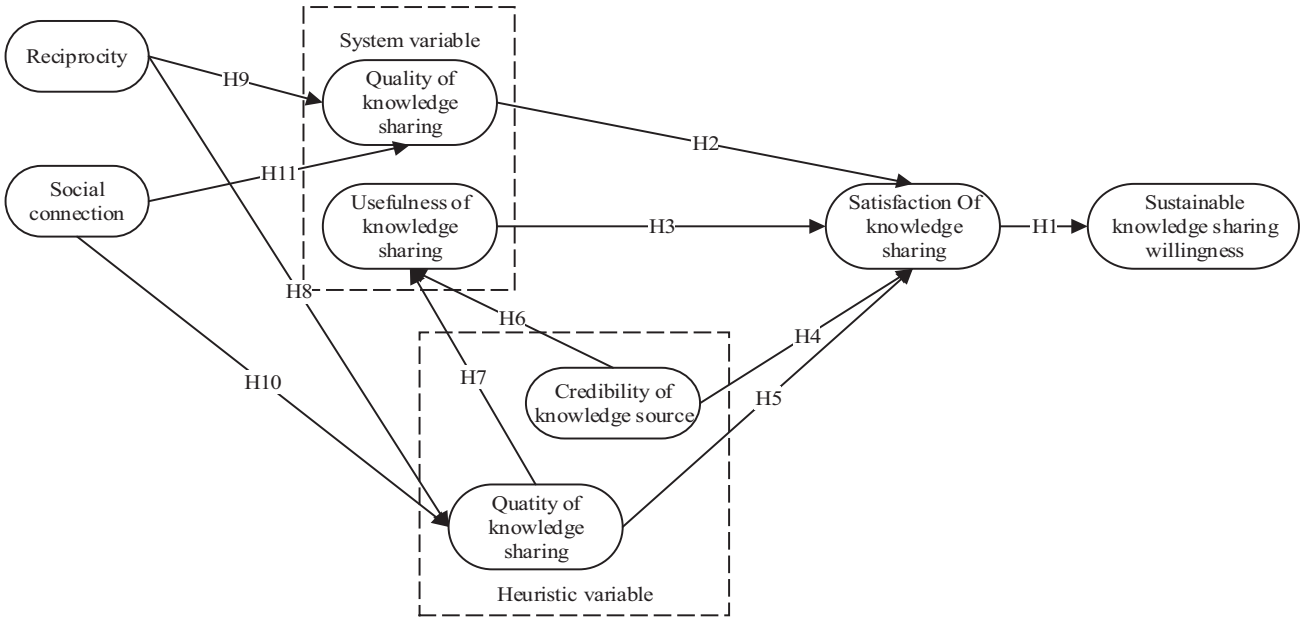

FIGURE 1 | Research model.

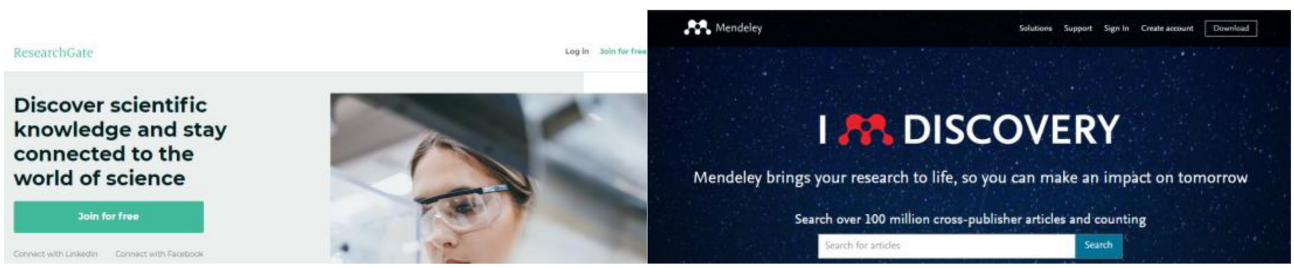

FIGURE 2 | Homepages of ResearchGate and Mendeley.

Data Processing

In order to determine whether the measurement has satisfactory psychometric attributes, SPSS 25.0 and Amos 24.0 were used to analyze the data. Firstly, descriptive statistics are used to analyze the data distribution and Cronbach α coefficient is used to evaluate the reliability of the scale, so as to judge whether the sample distribution is suitable for the next analysis. Secondly, analyze the correlation among the variables and judge whether the model can be constructed. Finally, the structural equation model is constructed by using Amos 24.0, and the relationship among the variables is discussed.

RESULTS

Common Method Deviation Test

In this study, the test scale is used to investigate, and all of them are conducted in a unified way. The content of the questionnaire, the characteristics of the participants and the environment of the test may cause covariation between the efficacy standard and the prediction, which may lead to deviation of the research results. In order to effectively verify the existence of common method deviation, Harman single factor test was adopted in this study, and exploratory factor analysis was made for all items. Through analysis, when the eigenvalue root is greater than 1, the variance explained by the first factor is 17.43% $<$ 40%. Therefore, there is no serious common method de-viation among the variables in this study.

Reliability and Validity Test of the Measurement Model

The reliability of the measurement model was measured by average variance extracted (AVE), composite reliability (CR), and Cronbach Alpha, with the lowest values of 0.5, 0.7, and 0.7, respectively. As shown in **Table 1**, the AVE value of all variables is greater than 0.7, the CR of all variables is greater than or equal to 0.886, and the Cronbach's Alpha of all variables is greater than or equal to 0.777, indicating that the measurement model has good reliability.

The validity of the measurement model includes content validity and construct validity. Content validity examines the comprehensiveness and representativeness of the content of the measurement indicators. As the measurement items of all variables come from existing research and are pre investigated in advance, the clarity and relevance of the measurement variables are guaranteed. Construction validity includes aggregation validity and differentiation validity. Aggregation validity is measured by AVE, and the threshold value of AVE is 0.5. According to **Table 1**, all AVE values are between 0.711 and 0.901, indicating that aggregation validity is good. It can be seen from **Table 2** that the square root of the mean-variance of all variables is greater than the correlation coefficient, so the discrimination validity is good.

TABLE 1 | Reliability test of the model.

Variable	Numbers	AVE	CR	Cronbach's Alpha
Sustainable knowledge sharing willingness	3	0.838	0.941	0.922
Usefulness of knowledge sharing	4	0.798	0.904	0.910
Quality of knowledge sharing	4	0.711	0.886	0.876
Quantity of knowledge sharing	4	0.812	0.921	0.933
Reciprocity	4	0.861	0.957	0.945
Satisfaction Of knowledge sharing	3	0.901	0.961	0.955
Social connection	4	0.891	0.959	0.948
Credibility of knowledge source	4	0.721	0.892	0.777

TABLE 2 | Correlation coefficient.

Variable	1	2	3	4	5	6	7	8
1. Sustainable knowledge sharing willingness	0.922							
2.Usefulness of knowledge sharing	0.656	0.910						
3.Quality of knowledge sharing	0.533	0.595	0.876					
4.Quantity of knowledge sharing	0.501	0.498	0.622	0.933				
5.Reciprocity	0.612	0.688	0.521	0.567	0.945			
6.Satisfaction of knowledge sharing	0.701	0.599	0.534	0.696	0.589	0.955		
7.Social connection	0.333	0.421	0.383	0.333	0.347	0.466	0.948	
8.Credibility of knowledge source	0.489	0.487	0.524	0.410	0.587	0.481	0.367	0.777

Fit Analysis of the Structural Model

Partial least square method is used to analyze the structural model, including path coefficient among variables, significance degree of the path (all significant paths are marked with * mark), and variance of variable interpretation (R2). The analysis results are shown in **Figure 3**.

The results of the structural model test show that 50.1% of the difference of sustainable willingness of knowledge sharing is caused by the satisfaction of knowledge sharing, and R2 (explained variance) of satisfaction of knowledge sharing is 54.6%, that is to say, 54.6% of the variance of satisfaction of knowledge sharing is explained by various heuristic factors and systematic variables, which shows that the structural model has better prediction effect. Besides, all hypotheses are verified. The satisfaction of knowledge sharing has a significant positive effect on the sustainable willingness of knowledge sharing ($\beta = 0.701$, $P < 0.001$). Hypothesis H1 is verified. Systematic factors and heuristic factors are the key predictors of satisfaction of knowledge sharing. Systematic factors include the quality of knowledge sharing and the usefulness of knowledge sharing, and their influence coefficients are 0.121 ($P < 0.05$) and 0.274 ($P < 0.001$), respectively. Heuristic factors include the quantity of knowledge sharing and the credibility of knowledge sources, and their influence coefficients are 0.444 ($P < 0.001$) and 0.141 ($P < 0.0$), respectively 1) ($\beta = 0.444$, $P < 0.001$), assuming that H2, H3, H4, H5 are all verified. The quantity of knowledge sharing and the credibility of knowledge source have significant positive effects on the usefulness of knowledge sharing, the influence coefficients are 0.374 ($P < 0.001$) and 0.322 ($P < 0.001$), respectively, assuming that H6 and H7 are tenable. In addition, the two social influence variables of reciprocity and social connection have a significant influence on some heuristic variables (quantity of knowledge sharing) and systematic variables (quality of knowledge sharing), and reciprocity has a significant influence on the quality of knowledge sharing ($\beta = 0.553$, $P < 0.001$). And the quantity of knowledge sharing ($\beta = 0.501$, $P < 0.001$) had a greater impact. The social connection had a smaller impact on the quality of knowledge sharing ($\beta = 0.221$, $P < 0.001$) and the quantity of knowledge sharing ($\beta = 0.218$, $P < 0.001$), assuming that H8, H9, H10, H11 were all tenable.

DISCUSSION

The HSMP Supports the Related Research of Online Knowledge Sharing in the Future Theory

With the continuous development of COVID-19, it will inevitably lead to an increase in the proportion of online academic exchanges in the future. Due to various discomforts caused by the initial online sharing, the publication of a large number of related studies from 2019 to 2021 can show that researchers attach importance to this issue. However, the existing literature is difficult to provide a reliable theoretical basis to ensure the scientific nature of the research. Therefore,

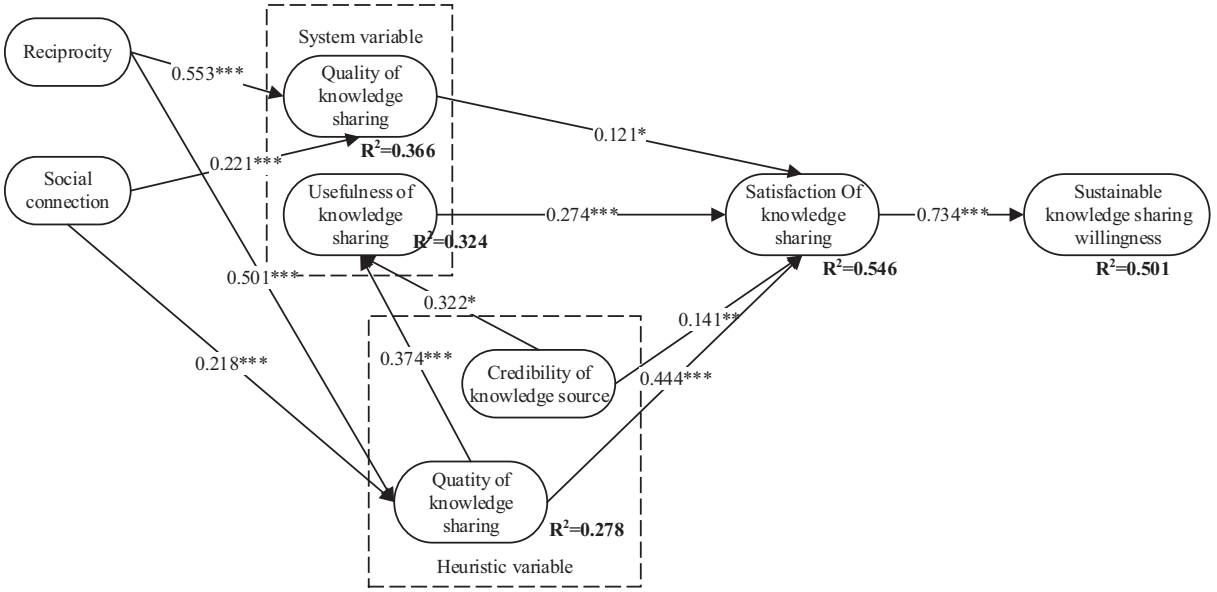

FIGURE 3 | Model results. *$p < 0.05$, **$p < 0.01$, ***$p < 0.001$.

although HSMP is more and more applied to the research of network information behavior, it is less applied in the field of knowledge sharing in virtual academic community, which is an innovation. In this paper, the satisfaction of knowledge sharing and sustainable willingness of knowledge sharing is regarded as a dual process, including heuristic and systematic behaviors, which are affected by heuristic cues (including two heuristic variables of reliability of knowledge source and quantity of knowledge sharing) and systematic cues (including two systematic variables of the usefulness of knowledge sharing and quality of knowledge sharing). Two heuristic variables have a significant impact on the usefulness of knowledge sharing, which is a system variable. The deviation effect of the HSMP is verified. It can be seen that the application of HSMP from the general rules of human behavior decision-making to explore satisfaction of knowledge sharing and sustainable willingness of virtual academic community can reveal the influence and mechanism of various rational and irrational factors on the satisfaction of knowledge sharing and sustainable willingness of virtual academic community. It can also provide a novel and interesting research perspective for more studies on epidemic situation and education in the future.

Practice Verifies the Influencing Factors of Sustainable Knowledge Sharing

In practice, managers of virtual academic community can make efforts to improve satisfaction of knowledge sharing and sustainable willingness of virtual academic community through four aspects:

Quality and Usefulness of Knowledge Sharing

Quality and usefulness of knowledge sharing are two systematic variables of satisfaction evaluation, which have an important impact on satisfaction. For new or unfamiliar virtual communities, users usually adopt systematic behavior mode in the process of knowledge sharing and satisfaction evaluation, mainly based on the quality and usefulness of knowledge sharing for decision-making, which consumes more cognitive ability and resources. Because the virtual academic community is a loose organization formed by self-organization, there is no mandatory constraint mechanism, and there may be intellectual property disputes, timeliness is not strong, innovation is not enough, and the relevance with the discussion topic is not strong in the process of knowledge sharing. At the same time, the amount of community knowledge is large and growing constantly, and community members are inconvenient to obtain high-quality knowledge, thus reducing the usefulness of knowledge sharing. In view of this, the virtual academic community can identify the potential high-quality content by using the combination of machine algorithm and artificial screening, use knowledge mining and semantic retrieval technology to achieve the rapid acquisition of community knowledge, and carry out semantic analysis and deep-seated aggregation of community knowledge, build a knowledge navigation system with interrelated content, multi-dimensional and multi-level, and provide deep-seated knowledge services To improve the effectiveness and usefulness of knowledge sharing.

The Credibility of Knowledge Source and Quantity of Knowledge Sharing

The credibility of knowledge source and quantity of knowledge sharing are two important heuristic variables. For virtual communities with a certain degree of social recognition, in the process of satisfaction evaluation and sustainable willingness formation of user knowledge sharing, community members usually follow the principle of minimum effort and tend to adopt heuristic behavior mode, mainly based on the source

(credibility) and surface characteristics (quantity of knowledge sharing) It costs less cognitive effort and resources to judge. Therefore, the managers of virtual academic community can reduce the cognitive burden of users by increasing the credibility of knowledge sources and the number of knowledge: first, adopt the real-name system to improve the credibility of users and build a high-quality community; second, use PageRank, hits and other link algorithms for reference, comprehensively consider the academic authority and community influence of users, and calculate the ranking value of community user credibility (Person Rank, PR); the third is to meet the user's human needs to share knowledge and build prestige as much as possible, learn from the experience of community, improve the possibility of new users being recognized, and encourage users to continue to participate in knowledge sharing activities.

The Satisfaction of Knowledge Sharing and Sustainable Willingness

Heuristic behavior and systematic behavior can occur at the same time. The process of satisfaction of knowledge sharing evaluation and sustainable willingness formation has the characteristics of both heuristic and systematic behavior patterns, making the results both intuitive and rational. Community members determine behavior patterns mainly according to the motivation and ability factors in specific situations and seek the relative optimal solution in the process of weighing the minimum cognitive effort and the maximum benefit. In this regard, managers of virtual academic community need to consider the balance between knowledge sharing benefits and cognitive costs, pay attention to collecting and saving knowledge sharing behavior tracks and relevant data, and use big data technology and methods to deeply mine the professional characteristics, research preferences and behavior habits of community members, so as to provide an intelligent recommendation of knowledge sharing, so that community members can have the minimum cognitive cost get the most from knowledge sharing.

Reciprocity and Social Connection

Heuristic cues and systematic cues are affected by external social capital. Reciprocity and social connection have a significant influence on the quantity and quality of knowledge sharing, and the influence of reciprocity is greater than that of social connection. Knowledge sharing in virtual academic community is a collective exchange behavior among members, and the pursuit of interests is the key factor to promote the exchange behavior. The interests here include not only material rewards, but also psychological rewards such as self-esteem, approval, support, and prestige, and psychological rewards are usually more important than material rewards. Because of this, the managers of virtual academic community need to take effective measures. For example, establish a weak relationship based on interest, hold offline activities, promote mutual communication and recognition, improve trust among members, enhance social contact and community activity among members, and improve the knowledge sharing effect of virtual academic community.

Knowledge Sharing Under Epidemic Situation Helps Online Academic Development

With the outbreak of the epidemic, more and more online tools have been developed. The main goal is to allow users to create and participate in academic activities through communication, sharing, collaboration, publishing, management and interaction. Among these key functions, sharing has always been regarded as an important component of social media, and the sustainable sharing will affect its future development trend. As one of the mainstream social media tools for academic communication, the sharing of knowledge and information has become one of its basic functions. Knowledge sharing is defined as the process of individuals spreading knowledge to others, which essentially shows that knowledge sharing needs social interaction. However, knowledge sharing involves the behavior that individuals make others have their own proprietary technology and information sources, so it is very important to promote personal willingness to share knowledge.

The results of this study show that researchers are optimistic about knowledge sharing in virtual academic communities. Online knowledge sharing makes it easy for researchers to obtain cutting-edge knowledge and encourage each other from other researchers, while cutting-edge knowledge and friendly interpersonal relationships can enable researchers to actively consider the value of knowledge sharing as an academic activity, and also help them to conduct academic research better under many difficulties caused by the epidemic. However, this social effect depends on whether researchers regard the platform as a shared platform, because different individuals may perceive the same technology differently, which may subsequently affect the way they interact with the technology. Therefore, the extent to which researchers think that the platform provides easy online knowledge sharing may also determine the possibility or even the sustainability of their willingness to regard the platform as a valuable academic tool. This is also a meaningful focus for further investigation in future research.

How to Effectively Build a Virtual Academic Community and Help Learning

With the outbreak of the epidemic, online learning platform and online effective learning have been widely concerned. For a wide range of academic researchers, a complete and effective academic community platform has become an indispensable tool for future research. How to create a complete academic community platform and improve the use effect of online learning should be discussed from three aspects: researchers' sustainable willingness to participate, academic community managers' attention and input support, and the quality of online learning products.

Firstly, the results of this study show that researchers' sustainable willingness to share knowledge is at a high level, which reflects that the reason why a platform is used for a long time is influenced by researchers' willingness to use it. Therefore, in the development of academic community, it is necessary to pay close attention to users' use feelings and problem feedback

at any time, and timely handle and solve problems to ensure that researchers' use feelings will not be greatly affected.

Secondly, the orientation and function of academic community need to keep pace with the times to ensure the forefront, which is consistent with the needs of researchers. Therefore, it involves the management and maintenance of academic communities by managers, who must ensure the smooth use of platform functions, update and expand the resources needed by researchers in a timely manner, and strictly control the protection of research data and scientific research achievements. That's why this research chooses ResearcheGate and Mendeley as research platforms, because they do well enough to ensure that there are millions of users.

Finally, if individuals want to ensure effective online learning, they should be clear about why they learn. Online learning requires a higher level of self-control. Therefore, researchers should make a complete study plan before studying. In the process of learning, the academic community can provide researchers with professionals in the same professional field, from which you can discuss and share the confusion and experience of learning, which will help you deepen understanding of the content and maintain continuous enthusiasm for learning. Mendeley, for example, can comment on the literature read online and share it with the study group in time. In addition to studying, it is difficult for us to communicate face to face due to the epidemic situation, and the online virtual academic community provides us with the function of online meeting. Therefore, researchers should keep an optimistic attitude toward learning and a correct willingness to share in order to ensure that everyone can obtain accurate information.

LIMITATIONS

There are some limitations in explaining the current study. First, during the period of COVID-19, data were available only through online tools. Although the scale of this study is submitted to the virtual academic community users to fill in and retrieve in time, there may be some deviation in the data basis. Secondly, the sample size of this study is limited. Perhaps a larger sample size will make this study more effective. Finally, although the results of this study confirm the relationship between sustainable share knowledge willingness and some variables, is this result more serious during the outbreak than before? Since this study cannot obtain pre epidemic data, it is impossible to compare and analyze the willingness to share knowledge before and after the outbreak, but this study can explore the future data after the epidemic situation is stable. Therefore, the future research focus of this paper will also explore whether the sustainable knowledge sharing willingness of virtual academic community will be different from that during the epidemic and whether there is a more direct relationship with other factors when the epidemic is over, offline academic exchanges and knowledge sharing activities are fully restored.

DATA AVAILABILITY STATEMENT

The original contributions presented in the study are included in the article/supplementary material, further inquiries can be directed to the corresponding author/s.

ETHICS STATEMENT

The studies involving human participants were reviewed and approved by the Ethics Committee of Nanjing Normal University. The patients/participants provided their written informed consent to participate in this study.

AUTHOR CONTRIBUTIONS

All authors listed have made a substantial, direct and intellectual contribution to the work, and approved it for publication.

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Conflict of Interest: The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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APPENDIX

TABLE TA1 | Scale of sustainable knowledge sharing in virtual academic community.

Serial number	Topic
1	I like to help others by sharing my knowledge.
2	I am confident that I can provide valuable knowledge to others.
3	I have the ability to provide valuable knowledge.
4	I believe that a solid knowledge base is easier to accept new knowledge.
5	I am good at sharing new knowledge to work or study.
6	I am good at applying new methods of knowledge sharing to work or study.
7	Shared knowledge is helpful to my work or study.
8	Shared knowledge is related to the topic.
9	Shared knowledge is rigorous and accurate.
10	Shared knowledge is complete.
11	Shared knowledge is timely.
12	Rich knowledge topics provided by virtual community.
13	Sufficient knowledge provided by virtual community.
14	The knowledge shared by virtual community contains abundant information.
15	The knowledge topic of virtual community updating and sharing.
16	I am willing to share knowledge.
17	I am not willing to share knowledge.
18	I would like to participate in the discussion of virtual community.
19	I would like to respond to the topic.
20	I am satisfied with virtual community products.
21	I am satisfied with virtual community service.
22	I am satisfied with the use of virtual communities.
23	I can find the same professional in the virtual community.
24	I have people in close contact with the virtual community.
25	I can build friendships in virtual communities.
26	I belong to a topic organization of virtual community.
27	The knowledge shared by virtual community is based on my willingness.
28	The knowledge shared by virtual community is authoritative.
29	Knowledge recognition of virtual community sharing is high.
30	The knowledge shared by virtual community should be trusted.

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