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The effectiveness of national-level containment and closure policies across income levels during the COVID-19 pandemic: an analysis of 113 countries

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Abstract

Despite heterogeneity in income levels, countries implemented similarly strict containment and closure policies to mitigate the COVID-19 pandemic. This research assesses the effectiveness of these containment and closure policies, which we defined as larger decreases in mobility and smaller COVID-19 case and death growth rates. Using daily data for 113 countries on mobility and cumulative COVID-19 case and death counts over the 130 days between February 15, 2020 and June 23, 2020, we examined changes in mobility, morbidity, and mortality growth rates across the World Bank's income group classifications. Containment policies correlated with the largest declines in mobility in higher income countries. High-income countries also achieved lower COVID-19 case and death growth rates than low-income countries. This study finds better epidemiological outcomes of containment and closure policies for higher income countries than lower income countries. These findings urge policymakers to consider contextual differences, including levels of economic activity and the structure of the economy, when crafting policies in response to public health emergencies.

Keywords: COVID-19, international health policy, social epidemiology, effectiveness, socio-economic, World Health Organization

Key messages

- Differences in country-level income were ignored in policy responses to COVID-19.
- Containment and closure policies were more effective in high-income countries.
- Contextually inappropriate policies may exacerbate poverty and cause unnecessary death.

Introduction

Since the first reported cases in December 2019, the COVID-19 pandemic has spread worldwide, exceeding 100 000 000 cases by January 26, 2021 (Dong *et al.*, 2020). Cases outside of China were initially concentrated in high-income countries, including Italy, France and the United Kingdom, where incidence rates and death rates were higher than those in lower income countries (Sabawoon, 2020). However, higher levels of preexisting health disparities, relatively weaker health systems and large immunocompromised populations due to malnutrition, anaemia, malaria, HIV/AIDS and tuberculosis facilitated transmission in lower income countries (Kaseje, 2021; Ahmad Lone and Ahmad, 2020). By February 2021, Asia had reported more than 23 million cases, South America

had reported 15.9 million and Africa had reported 3.5 million (Dong *et al.*, 2020).

On March 11, 2020, the World Health Organization (WHO) validated the cross-border threat of COVID-19 by declaring it a pandemic (World Health Organization, 2020b). Due to the highly contagious nature of this infection and the lack of previously developed or readily available vaccines or treatments, precautionary measures became essential in the pandemic response at international, national, and local levels. COVID-19 spreads through respiratory droplets, making policymakers focus on limiting close contact to control the spread. The success of curbing transmission through strict population movement restrictions, isolation and quarantine in early epicentres, including China and Europe, set a precedent (Kraemer *et al.*, 2020; Vokó and Pitter, 2020; Vinceti *et al.*, 2020; Alfano and Ercolano, 2020). Many countries followed suit and sought to halt transmission and reduce the burden on the health system by implementing comprehensive containment policies, including domestic and international travel restrictions, public event cancellations and school and workplace closures. Despite important socioeconomic differences between countries, countries exhibited 'herd behaviour' when implementing containment policies in response to COVID-19 (Hale *et al.*, 2020a). After early rises in the stringency of containment policies in Southeast Asia, countries reached similarly high levels of stringency in mid-March irrespective

of their income level or the date of their first COVID-19 death.

This standardization of pandemic response guidelines overlooks differences in countries' economic activity, demography, political structure, health system strength and cultural characteristics (Kaseje, 2021). Whereas social distancing and lockdowns may be feasible in some settings, similar policies may be impractical or even harmful in others. The majority of labourers in developing countries work in the informal economy, with informal employment constituting 86% of total employment in Africa, 67% in Southeast Asia and 54% in Latin America (International Labor Organization, 2018). Those employed by the informal economy may not have the option to stay home, and governments may have limited funds or disbursement mechanisms to mitigate the consequences of containment policies through social assistance. Given the disproportionate risk for older populations of contracting COVID-19, the trajectory of the pandemic in each country is also shaped by demographics (World Health Organization, 2020e). The median age of the population in Africa is 19.7 years, compared to 42.5 years in Europe (United Nations, 2019). Additionally, only 3% of the population in sub-Saharan Africa is over 65 years, compared with 16.62% in Europe and Central Asia (World Bank, 2020). Further, staying home may not effectively prevent the virus from spreading in dense urban settings. The larger average size of families in low-income countries may facilitate transmission even with strict containment policies in place. COVID-19 is placing severe strain on health care systems globally; however, the strain is particularly acute on the already limited health care capacity in lower income countries.

Research has confirmed that social distancing successfully reduces the transmission, severity and deaths associated with COVID-19 (Matrajt and Leung, 2020). Despite this evidence supporting containment policies, scepticism abounds over the appropriateness of such policies in low-income countries (Barnett-Howell and Mobarak, 2020; Ayyub, 2021; Saleh and Cash, 2020; Glassman *et al.*, 2020; El-Erian, 2020; Mobarak and Barnett-Howell, 2020). Income-level considerations are especially critical given that the most effective containment policies promoted by current research also have the most significant consequences on economic activity (Pragyan *et al.*, 2020). Studies have found that contextual differences correlate with different pandemic outcomes. In Latin America and Africa, higher intensities of regional poverty correlated with smaller decreases in individuals' work-related mobility during the pandemic (Bargain and Aminjonov, 2020a). Chilean containment policies significantly reduced COVID-19 cases in higher income municipalities, while similar policies did not affect lower income areas (Magdalena, 2021). A study of 111 countries found that democracies and collectivist societies experienced larger declines in mobility than autocracies and individualist societies (Frey *et al.*, 2020). Additionally, higher levels of political trust in Europe were associated with greater decreases in mobility and, according to suggestive evidence, smaller increases in COVID-19 growth rates relative to low-trust regions (Bargain and Aminjonov, 2020b). Accounting for the contextual differences between countries, the correlation between expected pandemic response policies and actual policies is positive but low (Phadnis and Kudligi, 2020). This finding suggests that governments may ignore important domestic factors when implementing containment policies.

With the novelty and severity of the COVID-19 pandemic, many countries turned to the WHO for guidance. The WHO has advised governments to develop their pandemic response according to the state of transmission in their jurisdiction and the capacity of the health system (World Health Organization, 2020d,f). In some cases, such as localities with uncontrolled spread of COVID-19 and overburdened health systems, the WHO has suggested strict movement restrictions to reduce transmission (World Health Organization, 2020f). However, the WHO has not emphasized the importance of considering socioeconomic factors when crafting effective pandemic responses. The WHO has received criticism for its bias towards China while leading the global pandemic response (Babones, 2020) and neglecting contextual differences when issuing international guidelines (El-Erian, 2020). Understanding the impact that country income level has on the effectiveness of containment policies during COVID-19 will improve the applicability of the WHO's international guidance regarding non-pharmaceutical and societal interventions across country contexts. This insight is especially relevant because international organizations, such as the WHO, often inform the policymaking process at the country level (Dolowitz and Marsh, 2000; Tervonen-Gonçalves and Lehto, 2004; Schneider *et al.*, 2006; Brooks, 2005; Ward and Cao, 2012; Füglistler, 2012). Leading actors such as the WHO can encourage the diffusion of appropriate emergency mitigation policies by tailoring their international guidance to relevant economic considerations.

There is a lack of research on the impact of containment and closure policies and outcomes by country income level. Studies have predicted that social distancing guidelines would more successfully save lives, improve welfare and prove economically viable in high-income countries compared to low-income countries (Barnett-Howell and Mobarak, 2020; Alon *et al.*, 2020). However, few studies have compared the actual epidemiological outcomes of these policies. Additionally, several studies have focused on developed countries, such as the USA and Europe (Abouk and Heydari, 2020; Bargain and Aminjonov, 2020b; Sabat *et al.*, 2020; Barrios *et al.*, 2021; Chan *et al.*, 2020). Few studies have investigated developing countries, and even fewer have directly compared outcomes between developed and developing countries. Further, many African countries implemented swift and even preemptive containment and closure policies during the initial wave of COVID-19 cases in early 2020. However, given the social and economic disruption of these policies, most African countries did not reinstate lockdowns to mitigate the second surge in cases beginning in late 2020 (Nordling, 2020). More research is needed to understand the effectiveness of these containment and closure policies in different economic settings to avoid trial-and-error policymaking during future public health emergencies. The 2014 Ebola outbreak in West Africa spurred research on the association between political structure and social resistance to public health measures (Wilkinson and Fairhead, 2017) and the determinant influence of religious and traditional practices on health protocols (Manguvo and Mafuvadze, 2015). However, the accommodation of contextual differences in policy responses during the COVID-19 pandemic remains underexplored.

This research will address this gap in knowledge by assessing the association between country income level and the effectiveness of containment and closure policies implemented in response to COVID-19. Effectiveness is defined

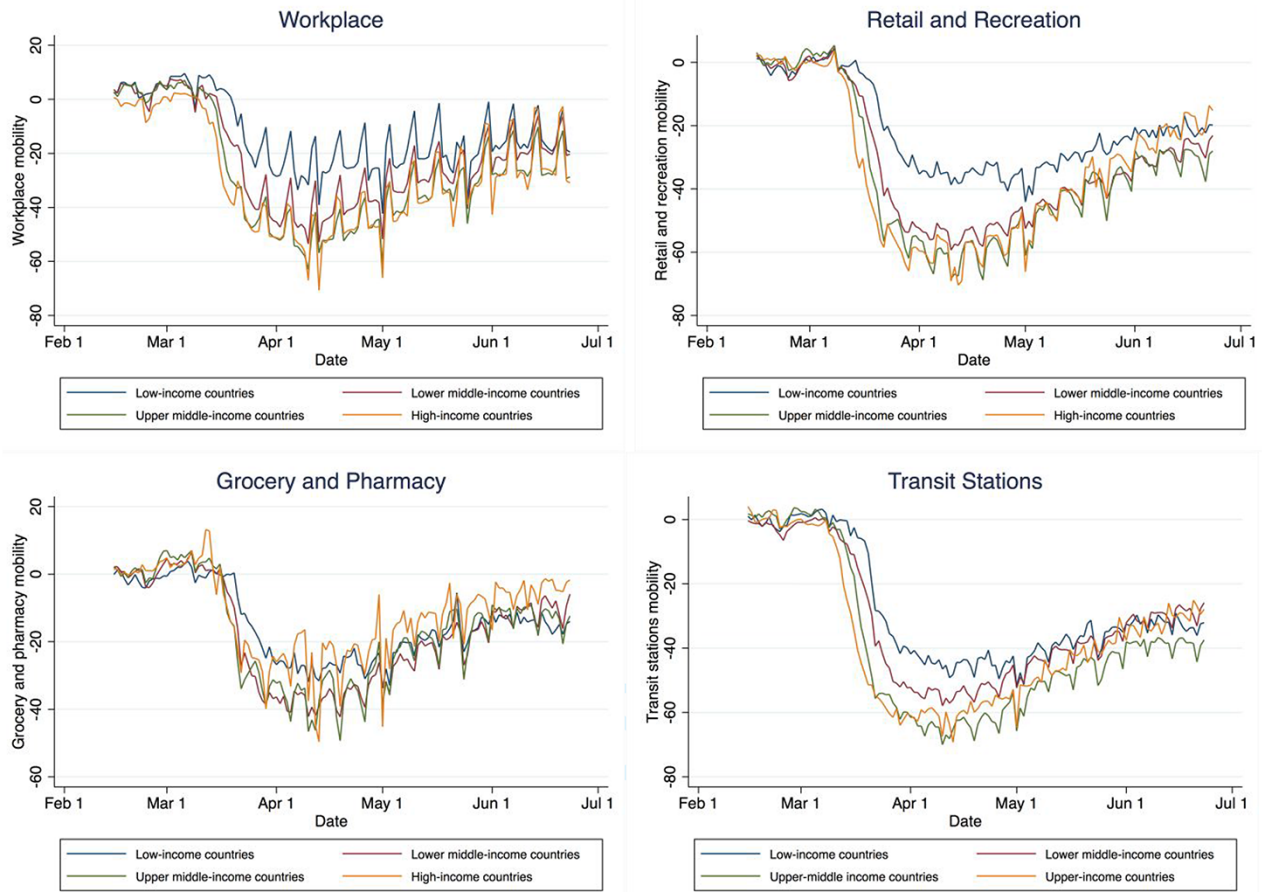


Figure 1. Mobility during the COVID-19 pandemic

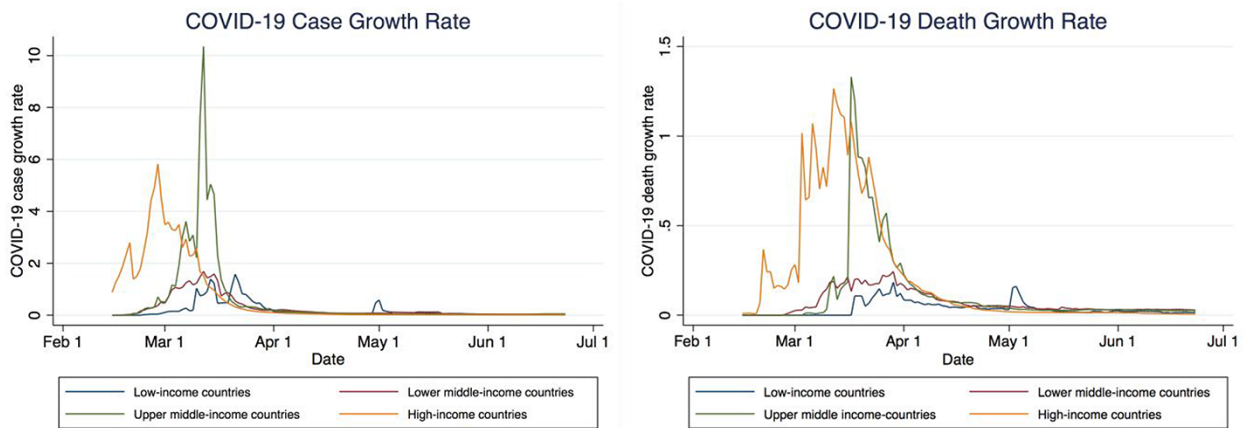


Figure 2. COVID-19 case and death growth rates

in this study as larger decreases in mobility and smaller COVID-19 case and death growth rates.

Methods

Data sources

We analysed COVID-19 containment and closure policy effectiveness by comparing trends in three outcomes: mobility, COVID-19 case growth rates and COVID-19 death

growth rates (Figure 1). We drew mobility data from country-level COVID-19 Community Mobility Reports from Google, which aggregate anonymized location history data from users’ mobile devices (Google, 2020). Mobility reports measure changes in the number of visits and length of stay within six location categories: (1) workplaces, (2) retail and recreation, (3) grocery and pharmacy, (4) transit stations, (5) parks and (6) residential areas. The resulting metric is a percent change that compares daily mobility to average mobility

from January 3 to February 6, 2020. Adopting a similar approach to Sulyok and Walker (2020), we analyse the four categories of mobility that reflect activity outside of the home: workplaces, retail and recreation, grocery and pharmacy and transit stations. We expect they would correlate positively with COVID-19 transmission.

The Center for Systems and Science Engineering (CSSE) at Johns Hopkins University's time-series data provided cumulative totals of COVID-19 cases (Figure 2) and deaths by country (Dong *et al.*, 2020). The CSSE pools data from multiple sources, including the WHO, the European Centre for Disease Prevention and Control and the US Centers for Disease Control and Prevention, to produce daily country totals of confirmed cases and deaths. Due to inconsistencies in countries' COVID-19 reporting criteria, testing errors and retrospective corrections to avoid double-counting, some daily incidence rates calculated using these data are negative. To smooth the data, we adopt the methodology of Bargain and Aminjonov (2020b) and analyse the trajectory of the pandemic at the country level by using a growth rate measure. We utilize a 2 week case growth rate based on WHO reports defining the incubation period for COVID-19 as 14 days (World Health Organization, 2020c) and a 2 week death growth rate based on WHO reports defining the time from infection onset to death as 2 to 8 weeks (World Health Organization, 2020a). We calculate growth rates by comparing the cumulative number of confirmed cases or deaths to that of 2 weeks ahead and dividing the corresponding growth rate by 14 to estimate a daily upcoming growth rate.

To determine the timing of the implementation of containment and closure policies, we drew on the Oxford COVID-19 Government Response Tracker, which assesses the stringency of COVID-19 response policies (Hale *et al.*, 2020b). Country-specific days for containment and closure policy implementation were assigned according to the first day that a country received a policy stringency rating above 0 in the stay-at-home requirement domain. Countries were categorized as low-, lower middle-, upper middle- and high-income based on World Bank income group classifications (World Bank, 2020).

Statistical analysis

The final sample consists of 113 countries over 130 days (February 15, 2020–June 23, 2020), resulting in a country-day panel of 14 690 observations. Three countries were excluded from the final dataset—Benin, Zimbabwe and Mauritius—because of negative 2 week COVID-19 case growth rates. Using a difference-in-differences design, we analysed the effectiveness of COVID-19 containment and closure policies by comparing trends in three outcomes (mobility, COVID-19 case growth rates and COVID-19 death growth rates) before and after the implementation of a containment and closure policy in low-, lower middle- and upper middle-income countries, compared with high-income countries. We compared exposure to containment and closure policies at a national level while controlling for day and country-level characteristics. Additional analyses tested underlying assumptions and the robustness of our findings to alternate assumptions and model specifications.

To estimate the effectiveness of containment and closure policies on mobility, we used a time-series linear regression model in the form:

$$Mobility_{ct} = \beta_0 + \beta_1(IncomeGroup_c) + \beta_2(Policy_{ct}) + \beta_3(IncomeGroup_c)*(Policy_{ct}) + \theta_t + \Delta_c + \mu_{ct}$$

In this model, the subscripts *c* and *t* refer to the country and time (e.g. day), respectively. In this model, *Mobility_{ct}* is the percent change in mobility calculated as the change between the current level of mobility and the level of mobility from January 3 to February 6, 2020. We run separate regressions for *Mobility_{ct}* defined as mobility from: (1) workplaces, (2) retail and recreation, (3) grocery and pharmacy and (4) transit stations. *IncomeGroup_c* is a categorical variable that defines each country as either: low-income, lower middle-income, upper middle-income or high-income country. *Policy_{ct}* is equal to 1 if a country's containment and closure policies were in effect and 0 otherwise. Identification of the policy impact comes from the variation in policy timing across countries and its independence from counterfactual outcomes across countries (*Policy_{ct}*). The interaction with countries' income categories (*IncomeGroup_c*)*(*Policy_{ct}*) deconstructs the treatment effects across these categories.

Day (θ_t) and country (Δ_c) fixed effects control secular time trends common to all countries and time invariant national differences. Models for the two other outcomes were analogous to the above equation, where *COVIDCaseRate_{ct}* and *COVIDDeathRate_{ct}* are both 2 week growth rates. We adjusted standard errors for clustering by country and performed all analyses using Stata version 16.

Results

Table 1 presents descriptive statistics that summarize the characteristics and distribution of values of key variables in the sample. In our sample of 113 countries, 8.85% were classified as low-income, 24.78% as lower middle-income, 27.43% as upper middle-income and 38.94% as high-income. The average numbers of COVID-19 cases on the previous day steadily increased by country income classification from 1004 in low-income, to 6836 in lower middle-income, 21 416 in upper middle-income and 42 983 cases in high-income countries. The average numbers of COVID-19 deaths on the previous day followed a similar pattern, with low-income countries reporting the least number of deaths and high-income reporting the most.

Table 2 presents the average effects of the policy changes across all countries. A statistically significant decrease occurred in all four mobility measures, including workplace, retail and recreation, grocery and pharmacy and transit station. Columns 1–4 indicate that countries with containment and closure policies experienced declines in mobility to workplaces (14.6 percentage points, $P < 0.01$), retail and recreation locations (18.7 percentage points, $P < 0.01$), grocery stores and pharmacies (8.6 percentage points, $P < 0.01$) and transit stations (18.8 percentage points, $P < 0.01$). Columns 5 and 6 continue to examine the average treatment effect of the containment and closure policies by assessing population-level measures of morbidity and mortality. Results indicate that countries that implemented containment and closure policies experienced a significant decrease (2.1 percentage points, $P < 0.01$) in their COVID-19 case growth rates and, although not statistically significant, a slight decrease in COVID-19 death growth rates (−0.1 percentage points).

Table 1. Descriptive statistics summarizing the characteristics and distribution of values of key variables in the sample

Variable	Number of Obs.	Percent of sample (%)	Minimum	Maximum	Mean	Standard deviation
Low-income	10	8.85				
Lower middle-income	28	24.78				
Upper middle-income	31	27.43				
High-income	44	38.94				
COVID-19 cases on the previous day:						
Low-income	1300		0	29 157	1004.15	3297.88
Lower middle-income	3640		0	440 215	6836.69	29 565.86
Upper middle-income	4030		0	1 106 470	21 416.39	83 357
High-income	5720		0	2 305 259	42 983.33	178 627.9
COVID-19 deaths on the previous day:						
Low-income	1300		0	598	24.39	63.81
Lower middle-income	3640		0	14 011	187.93	854.96
Upper middle-income	4030		0	51 271	817.71	3759.18
High-income	5720		0	120 845	3220.84	11 735.67

Table 2. The effectiveness of COVID-19 containment policies

	Dependent variable					
	Workplace mobility	Retail and recreation mobility	Grocery and pharmacy mobility	Transit station mobility	COVID-19 case growth rate	COVID-19 death growth rate
	(1)	(2)	(3)	(4)	(5)	(6)
Policy	-14.597*** (2.749)	-18.718*** (3.501)	-8.609*** (2.501)	-18.756*** (3.221)	-2.070*** (0.498)	-0.059 (0.154)
Low-income x policy	8.328* (4.632)	9.408* (5.136)	-1.322 (4.272)	2.400 (4.233)	2.193*** (0.491)	0.400*** (0.125)
Lower middle-income x policy	-1.671 (3.706)	-3.578 (4.317)	-9.981** (4.024)	-0.530 (3.610)	2.001*** (0.487)	0.403*** (0.127)
Upper middle-income x policy	-4.430* (2.471)	-3.937 (3.200)	-6.817** (2.886)	-6.408** (2.934)	0.844 (0.912)	0.376*** (0.125)
Constant	-13.967*** (1.607)	-18.745*** (2.029)	-5.928*** (1.553)	-21.272*** (1.999)	1.325*** (0.268)	0.013 (0.087)
R ²	0.754	0.786	0.630	0.817	0.093	0.134
n	14 690	14 690	14 686	14 690	14 690	14 690
Day fixed effects	Yes	Yes	Yes	Yes	Yes	Yes
Country fixed effects	Yes	Yes	Yes	Yes	Yes	Yes

Notes: The reference group includes high-income countries. Models (1) through (4) estimate the association between containment policies and the four categories of mobility. Models (5) and (6) estimate the association between containment policies and COVID-19 case and death growth rates. Robust standard errors are recorded in parentheses. Significance level: *** $P < 0.01$, ** $P < 0.05$, * $P < 0.1$.

Our main coefficients of interest are the interactions with countries' income categories, which compared the changes in transmission, morbidity and mortality between lower income countries and higher income countries (in terms of country income classification) after implementing containment and closure policies. Table 3 presents the results of *t*-tests to compare the treatment effect for each income classification. While the effects are not all significant, there is a general pattern of decreasing mobility and morbidity and slight changes in mortality when moving from lower income to higher income countries. For all types of mobility (workplace, retail and recreation, grocery and pharmacy and transit stations), estimates indicate that higher income countries decreased mobility more than lower income countries. This pattern is particularly pronounced for retail and recreation mobility, where the point estimate ranges from a decrease of 9.3 percentage points ($P < 0.10$) in low-income countries to a decrease of 22.7 percentage points ($P < 0.01$) in upper

middle-income countries. This pattern is also prominent for transit mobility, where estimates indicate a 16.4 percentage point reduction in low-income countries ($P < 0.01$) and a 25.2 percentage point reduction in upper middle-income countries ($P < 0.01$). Estimates are similar for the workplace as well as grocery and pharmacy mobilities. Although not statistically significant, the estimates for COVID-19 growth rates indicate that low-income countries had higher case growth rates (0.12 percentage points) than higher income countries after containment and closure policies were implemented, with case growth rates reduced in lower middle- (0.07) and upper middle-income countries (1.23 percentage points). Compared to the strong and significant decreases in mobility and the smaller yet still evident pattern of decreasing case growth rates when moving from lower income to higher income countries, the pattern was less clear for death growth rates. Changes in mortality were significant across country income levels. However, the differences were slight, with death growth rates

Table 3. The effectiveness of COVID-19 containment policies

	Dependent variable					
	Workplace mobility	Retail and recreation mobility	Grocery and pharmacy mobility	Transit station mobility	COVID-19 case growth rate	COVID-19 death growth rate
	(1)	(2)	(3)	(4)	(5)	(6)
Policy + low-income x policy	-6.269 (4.576)	-9.310* (5.084)	-9.931** (4.184)	-16.355*** (4.391)	0.123 (0.225)	0.341*** (0.119)
Policy + lower middle-income x policy	-16.268*** (3.513)	-22.296*** (4.085)	-18.590*** (3.853)	-19.286*** (3.661)	-0.069 (0.190)	0.344*** (0.123)
Policy + upper middle-income x policy	-19.026*** (2.793)	-22.656*** (3.549)	-15.426*** (3.061)	-25.164*** (3.575)	-1.226 (0.875)	0.317** (0.128)

These results were obtained through *t*-tests for the linear combinations of the coefficients.

Robust standard errors are recorded in parentheses.

Significance level: *** $P < 0.01$, ** $P < 0.05$, * $P < 0.1$.

ranging from 0.34 percentage points ($P < 0.01$) in low-income countries to 0.32 percentage points in upper middle-income countries ($P < 0.05$). In terms of epidemiological outcomes, differences associated with country income levels were more pronounced for measures of transmission and morbidity than for mortality. Despite having higher case growth rates, lower income countries may have comparably small death growth rates if other contextual factors, such as the relatively younger populations in lower income countries, lower the risk of developing severe COVID-19 cases.

The specifications in Tables 4 and 5 serve as specification checks and test for possible biases in these results. We focus first on the average effects of the policy changes (Table 4). Models in Columns 1–6 use an alternate definition of the treatment period defined as a region-average lockdown day. The region-average lockdown day likely adjusts for delays between the implementation of policies and the observed response. The findings for grocery and pharmacy mobility remain stable, whereas the estimated effects on the workplace, retail or recreation and transit mobility remain statistically significant but become smaller. The morbidity measure (COVID-19 case growth rates) remains stable, whereas the mortality measure (COVID-19 death rates) becomes more substantial and more significant. Columns 7 and 8 test the robustness of our results by substituting 1 week growth rates for the 2 week case and death growth rates used in the main specification. Columns 9 and 10 further expand this definition by substituting 3 week case and death rates. To keep the exclusion criteria consistent with that of our main specification, we exclude countries with negative 2 week case growth rates. Therefore, our samples include 110 countries and 114 countries in our 1 week and 3 week growth rate analyses, respectively. In general, the 1 week case and death growth rates were smaller compared to the primary model. The 3 week growth and death rates were slightly larger.

As previously mentioned, we wanted to investigate the possibility that the effects of the policy change might be more evident in higher income countries than lower income countries. To further investigate the sensitivity of our results, we implement the same sensitivity checks outlined in Table 4

and present the results of *t*-tests (Table 5) to compare the treatment effect for each income classification. In general, the changes in mobility remain significant and become smaller, except for grocery and pharmacy mobilities. The changes show decreased strength of mobility and morbidity when moving from higher income to lower income countries. Consistent with our main specification, death growth rates are lowest in higher income countries. However, the magnitude of the differences in mortality between country income classifications is slightly larger than in our main specification.

The validity of the empirical approach depends on the assumption that in the absence of the intervention, the differences in mobility, morbidity and mortality between the treated and comparison groups would have increased or decreased at the same rate in both groups. This parallel trends assumption can be difficult to test since we do not have multiple waves of outcome data before the intervention. The assumption can be partially checked by examining pre-intervention trends, both statistically and graphically. As the policies were passed at different times between February 15, 2020 and June 23, 2020, we assume that the placebo cut-off date is March 11, 2020, the date the WHO declared COVID-19 a pandemic. We then estimated regression models of each outcome on observation week and included an interaction term with a binary indicator of whether the observation was from a country with an intervention (same as the *Policy* variable in the primary specification) and an interaction between the two variables (*Policy*Week*). We also compared these results with a model including country-fixed effects. The interaction term's coefficient was not statistically significant, which is a sign that pre-intervention trends were relatively similar. It is important to note that the parallel trends assumption for the death outcome measure did not hold using statistical measures. Tests of this assumption should be interpreted with caution given the limited availability of pre-intervention data. In particular, mortality estimates should be interpreted with caution as the associations between the interventions and mortality may be biased. In addition to using formal statistical tests, we also assessed pre-intervention trends graphically.

Table 4. Specification checks to test the effectiveness of COVID-19 containment policies

	Dependent variable									
	Workplace mobility (1)	Retail and recreation mobility (2)	Grocery and pharmacy mobility (3)	Transit station mobility (4)	COVID-19 case growth rate (5)	COVID-19 death growth rate (6)	COVID-19 1 week case growth rate (7)	COVID-19 1 week death growth rate (8)	COVID-19 3 week case growth rate (9)	COVID-19 3 week death growth rate (10)
Policy	-8.493 ^{***} (2.302)	-13.952 ^{***} (3.027)	-8.605 ^{***} (2.673)	-13.500 ^{***} (2.902)	-1.816 ^{***} (0.395)	-0.345 ^{***} (0.138)	-0.576 ^{***} (0.130)	0.025 (0.049)	-5.769 ^{***} (1.579)	-0.467 (0.468)
Low-income x policy	6.392	7.804	-1.837	1.478	2.016 ^{***}	0.563 ^{***}	0.584 ^{***}	0.114 ^{***}	6.359 ^{***}	1.215 ^{***}
Lower middle-income x policy	(4.132)	(4.978)	(4.285)	(4.494)	(0.386)	(0.137)	(0.141)	(0.035)	(1.559)	(0.412)
	-1.161	-3.690	-8.820 [*]	0.117	1.710 ^{***}	0.486 ^{***}	0.552 ^{***}	0.119 ^{***}	5.767 ^{***}	1.195 ^{***}
Upper middle-income x policy	(4.227)	(5.014)	(4.543)	(4.610)	(0.400)	(0.141)	(0.131)	(0.035)	(1.575)	(0.415)
	-6.973 ^{***}	-7.228 ^{**}	-8.674 ^{***}	-9.506 ^{***}	0.641	0.466 ^{***}	0.300 [*]	0.105 ^{***}	2.538	1.155 ^{***}
Constant	(2.537)	(3.306)	(2.974)	(3.190)	(0.864)	(0.143)	(0.174)	(0.034)	(2.842)	(0.417)
	-17.845 ^{***}	-21.451 ^{***}	-5.751 ^{***}	-24.471 ^{***}	1.234 ^{***}	0.173 ^{***}	0.405 ^{***}	0.011	3.381 ^{***}	0.086
	(1.290)	(1.565)	(1.365)	(1.536)	(0.185)	(0.057)	(0.059)	(0.031)	(0.756)	(0.229)
R ²	0.744	0.775	0.625	0.805	0.089	0.140	0.137	0.185	0.073	0.096
n	14 690	14 690	14 686	14 690	14 690	14 690	14 300	14 300	14 820	14 820
Day fixed effects	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Country fixed effects	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes

Notes: The reference group includes high-income countries. Models (1) through (4) estimate the association between containment policies and the four categories of mobility. Models (5) and (6) estimate the association between containment policies and COVID-19 case and death growth rates. Models (1) through (6) test an alternate definition of the treatment period, using a region-averaged lockdown day according to the World Bank's region classification. Models (7) and (8) substitute 1 week growth rates for the 2 week case and death growth rates used in the main specifications, respectively. Models (9) and (10) substitute 3 week growth rates for the 2 week case and death growth rates used in the main specifications, respectively. All models stratify the policy effects by income group. Robust standard errors are recorded in parentheses. Significance level: ***P < 0.01, **P < 0.05, *P < 0.1.

Table 5. Specification checks to test the effectiveness of COVID-19 containment policies

	Dependent variable									
	Workplace mobility (1)	Retail and recreation mobility (2)	Grocery and pharmacy mobility (3)	Transit station mobility (4)	COVID-19 case growth rate (5)	COVID-19 death growth rate (6)	COVID-19 1 week case growth rate (7)	COVID-19 1 week death growth rate (8)	COVID-19 3 week case growth rate (9)	COVID-19 3 week death growth rate (10)
Policy + low-income x policy	-2.101	-6.148	-10.442**	-12.022***	0.200	0.218***	0.009	0.139***	0.590	0.748**
Policy + lower-middle-income x policy	(3.909) -9.654***	(4.646) -17.642***	(4.041) -17.425***	(4.130) -13.383***	(0.240) -0.106	(0.063) 0.141*	(0.088) -0.023	(0.044) 0.144***	(0.463) -0.002	(0.295) 0.727**
Policy + upper-middle-income x policy	(3.646) -15.466***	(4.184) -21.180***	(3.772) -17.279***	(3.800) -23.007***	(0.223) -1.175	(0.075) 0.122	(0.066) -0.275*	(0.045) 0.130***	(0.407) -3.231	(0.304) 0.687**
Policy	(2.645)	(3.064)	(2.746)	(3.092)	(0.730)	(0.087)	(0.147)	(0.047)	(2.572)	(0.321)

These results were obtained through *t*-tests for the linear combinations of the coefficients.

Robust standard errors are recorded in parentheses.

Significance level: ****P* < 0.01, ***P* < 0.05, **P* < 0.1.

Discussion

To our knowledge, this is the first paper to estimate the effectiveness of COVID-19 containment and closure policies on mobility, morbidity and mortality by country income classification. This study hypothesized that containment and closure policies would be more effective in higher income countries compared to lower income countries. Our analysis provides evidence that the policy effect on mobility is apparent as one moves from lower income to higher income countries. In general, the higher the income level, the less people moved after the policies were implemented. In terms of morbidity, results indicate a statistically insignificant pattern of decreasing strength across income classifications. There was more COVID-19 case growth in low-income countries and less growth in lower middle-income followed by upper middle-income countries, compared to high-income countries. Turning to the mortality findings, we would have expected a larger magnitude of difference between the death growth rates for each income classification, but we see almost identical effects moving from lower to higher income settings. We do not think this is driven solely by inadequate surveillance and low testing in resource-constrained settings. Instead, we think this finding is a reflection of the fact that resource-constrained countries tend to report lower mortality than the global trend due to the combined effects of weather, a younger population and a lower prevalence of underlying comorbidities associated with COVID-19 death such as diabetes and asthma (Njenga *et al.*, 2020). The unequal reductions of mobility and management of COVID-19 case growth rates are indications that strict containment and closure policies were not universally effective and that tailoring containment and closure policies to country income levels would improve the effectiveness of the emergency response. International organizations responsible for providing policy guidance, such as the WHO, must consider the unique conditions in lower income countries in addition to higher income countries, when proposing public health emergency response guidelines in order to accommodate contextual differences and maintain relevance across localities.

Other research might expand on the current study's approach or address its limitations. Because new data are generated daily, future studies might exploit additional data to investigate the effect of country income level on containment and closure policy effectiveness at different stages of the pandemic. Inconsistencies and errors in official reports of COVID-19 cases and deaths by country may have biased our results. Under-detection, limited testing capacities and discrepancies between countries or over time in the criteria for reporting cases and deaths introduced bias to the surveillance data (Ibrahim, 2020). Although the data used in this study reflect the most accurate data available, future studies may use corrected, updated daily cumulative and death case counts to assess the validity of our results. The lack of available data also leads us to focus on country-level data, which obscures sub-national inequalities. If disaggregated COVID-19 data becomes available for a large and representative sample of countries, the impact of containment and closure policies at the sub-national level could be studied with a similar approach. Another limitation is the community mobility data, which helps chart longitudinal trends in mobility by geography, but is limited (Grantz *et al.*, 2020). The data depend on user settings and connectivity for users who have

opted-in to location history for their Google account. There is bias in the population for which these data are available, so this may not represent the exact behaviour of a wider population. Also, these data only include in-country mobility. Cross-border mobility is essential in informing COVID-19 response. Policy decisions informed by mobile phone data should carefully consider which populations and behaviours would be excluded, viewing these data as complementary to existing surveillance systems. In the case of this research, this bias most likely causes our effects to be overestimated in low- and middle-income countries, where a larger, poorer portion of the population does not own a phone and is, therefore, excluded from the data set (Blumenstock and Eagle, 2010; Wesolowski *et al.*, 2012; 2013). As a result of known measurement issues with mobility data, we also focus on key measures of population-level health: morbidity and mortality. While our study tested the epidemiological outcomes of containment and closure policies, further research is needed to understand the economic costs of these policies. Restricting movement and shutting down portions of the economy may have exacerbated poverty rates, increased the prevalence of other illnesses or instigated civil conflict in some countries. Weighing changes in mobility and COVID-19 growth rates against these harmful outcomes will present a more comprehensive evaluation of the effectiveness of containment and closure policies.

Conclusion

We found that COVID-19 containment and closure policies were most effective with respect to mobility and morbidity in higher income countries compared to lower income countries. This finding suggests that policymakers must consider the unique conditions in lower income countries in addition to higher income countries to propose public health emergency response guidelines that accommodate contextual differences and maintain relevance across localities. Contextual differences between countries prevent the uniform effectiveness of strict containment and closure policies. Integrating factors such as the structure of the economy and the level of economic activity may inform a more comprehensive policy response. Thus, if policymakers and international organizations responsible for providing emergency mitigation guidance, such as the WHO, fail to consider a more nuanced approach, the result will be inappropriate policy implementation across country income levels that results in higher levels of transmission, morbidity and mortality. As we are limited in the precision of mobility and surveillance data, future research should further investigate the epidemiological outcomes of containment and closure policies during the COVID-19 pandemic. Future research should also examine the global diffusion of containment and closure policies to identify factors that led countries of various income levels to engage in herd behaviour.

Data availability

Google's Community Mobility Reports are publicly accessible at <https://www.google.com/COVID19/mobility/>. The University of Oxford Blavatnik School of Government's Oxford COVID-19 Government Response is publicly accessible at <https://www.bsg.ox.ac.uk/research/research-projects/>

[coronavirus-government-response-tracker](https://github.com/CSSEGISandData/COVID-19). The Center for Systems Science and Engineering at Johns Hopkins University's COVID-19 Data Repository is publicly accessible at <https://github.com/CSSEGISandData/COVID-19>. The World Development Indicators Database is publicly accessible at <https://data.worldbank.org/indicator/NY.GNP.ATLS.CD>. All data are fully available without restriction.

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Ethical approval

Ethical approval for this type of study is not required by our institute.

Conflict of interest statement

The authors declare that they have no conflict of interest.

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