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Un ringraziamento speciale alla mia famiglia,

in particolare, ai miei genitori per il vostro continuo supporto

e un grazie alle mie persone che mi sono state accanto

in questo percorso e in questi anni di vita.

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Firma (signature)

Francesca Martignago

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INTRODUCTION

Over the past few years, the issue about automation and robotization has become more and more central and debated globally.

From the First Industrial Revolution, in the mid-1700s, things changed drastically because of the discoveries and inventions like the steam engine and tools which speeded up production. However, most significant was the Second Industrial Revolution, one century after, with the introduction of steel, oil, chemicals and, especially, electricity. The first multinational companies were built, and new ways of working were organized like the assembly line system, used firstly by Ford in his factories. This moment of fervour was interrupted, in the 1914, by the outbreak of the First World War and, subsequently, of the Second World War (1939-1945). The wars caused terrible situations and regression until the years after the mid-1900s, when a recovery phase started with political and economic expansions of industrialized countries and technological progress, known as Third Industrial Revolution. This phase was characterized by the growth of the tertiary sector and the development of electronics, telematics, and information technology.

The last ten years, instead, have seen the development of innovations like the 3D printer, augmented reality, virtual reality, artificial intelligence and IoT (Internet of Things) systems. Especially, the latter is accused of having radically changed lots of different objects with which people interact every day.

Analysing these concepts in the industrial sphere, companies in the last years adopted increasingly more technological systems, implementing especially the production with robots. The growth of robotized machines in factories defines the increasing interest for this topic related to digital and technological transition, industrial developments, impacts on employment and wages. According to recent estimates, starting from 2000, up to 2019, the adoption of industrial robots in the world increased from about 80,000 a year to around 400,000, with a dramatic growth from 2010 onwards (IFR 2020).

The effects of technological innovation on labour depends on several aspects such as labour proficiency, structure of the labour market, employment structure within companies.

The debate is still open and there are different points of view on this topic from the more pessimistic to the more optimistic. Some research on the OECD countries demonstrates that robots and machines can generate from 9% to 47% of job losses. These tools, for that reason, have been described in a negative way, as work thieves, because they can substitute people on their jobs and generate unemployment. This idea brings with it a lot of worries and fears both for employees and for governments. On one side, people replaced by robots are without a job and without an income, on the other side, governments have to introduce new policies in order to reply to this situation where companies substitute workers with machines to avoid the high taxes of labour income which in turn generate hundreds of billion losses of tax revenues. Other studies are more optimistic demonstrating that automation can generate an increase of employment, creation of new jobs and industries and an aggregate positive effect for the society. Caselli et al. explains how robotization has to be considered a complementary tool to human work, generating new ways of working where people, who are led to learn new skills and how to interface with robots, can be reallocated in the same company or, at least, don't be fired.

In this scenario, this elaboration intends to present a cross-country analysis, by investigating the impact of some task-aggregated automated machines on employment dynamics considering variables such as educational level of employees, wages, labour force, and countries' specific characteristics. The analysis focuses on 30 countries, both developed and developing ones, in the period 2011-2018, and involves the creation of a dataset, which aggregates data from ILO (International Labour Organization) and World Bank. Moreover, it wants to explain the causal relationship between automation and employment.

Chapter 1 introduces the evolution of automation and robotization in the world with an overview of the Industrial Revolutions and how industrial robotics was developed and adopted in the XXI century.

Chapter 2 describes the most relevant literature in this field explaining the employment situation of different countries impacted by robotization and how wages are changed by those technological innovations. In addition, it summarises the main aspects that determine the positive or negative relationship between automation and employment, and which are the trends and future expected scenarios.

Chapter 3 reports the dataset and the data exploration method, Chapter 4 the data elaboration and the results of the cross-country analysis.

Chapter 5 describes the possible policies that countries are thinking to adopt in order to reply to the changes caused by automation and robotization on employment. Governments tax companies and workers within them, but if people are replaced by robots, how should the tax policy change?

CHAPTER 1: EVOLUTION OF AUTOMATION IN THE WORLD

1.1 - INDUSTRIAL REVOLUTIONS: AN OVERVIEW

Literally, the term automation is defined as "the use of technical and technological means and procedures, especially in the field of electronics, aimed at ensuring a process or operation in which human intervention is reduced or eliminated"[1].

The historical moment when this change first occurred, in the sense that a machine was used to accelerate human work, was during the First Industrial Revolution. There was a shift from a purely agricultural-craft system to a more industrial one characterized by the presence of inanimate machines, which perform part of the tasks previously carried out physically by men and animals.

From the second half of the 1700 in Great Britain, a series of innovations began to develop that involved machine tools and driving machines in the textile and heavy industry sectors (metallurgical and mechanical).

The pivotal invention, identifying the change that was taking place, was the steam engine, designed by James Watt in 1765. Thanks to this invention there was a radical change in energy production, which previously only saw the use of sources such as water or wind, not available in quantity, times and places where there was real need. Furthermore, as the revolution took place in England, a country rich in coal, the steam engine generated an incredible novelty.

In the same period, the introduction of carbon coke allowed a great development of the iron and steel industry, concomitant with the textile industry (power looms 1787).

Edmund Cartwright was the inventor of the mechanical loom, which was the first real tool comparable to the nowadays robots, capable of replacing the manual work of man following the principles of automation as it is defined today. While in India it took 100,000 hours of work to weave 100 pounds of cotton by hand, in Great Britain it took only 135.

In addition, the new scientific discoveries made it possible to explore different and unknown fields of science and the evolution of the scientific allowed to go deeper into the unexplored subjects.

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[1] Definition of automation: https://www.britannica.com/technology/automation

During the First Industrial Revolution, in fact, the scientific Galileo Galilei developed the scientific method, which can be considered the first move in the exploration and analysis of scientific events and processes.
These technological and scientific changes also had economic consequences.
The increased ability to create and produce goods, in conjunction with the development of trade and increases in exports of wool and cotton, generated strong economic growth within the country.
This surplus was a booster for the agricultural and, especially, the industrial sector. Furthermore, London became the most important financial centre of the world making England one of the most industrialised cities on the planet.
In this context, the middle class was born, with large new landowners and industrial owners who built a profit-oriented system, with deep changes for employment and labour conditions in compared to the past.
Factories were populated by men, women, and children who worked for 12 to 16 hours per day; the salary enabled subsistence, women and children were paid less than men. The workplaces were overcrowded and unhealthy. Rest was limited to a few hours dedicated to sleep, since meals were also taken in the factory, and suburbs in the cities basically became dormitories for working-class families. The revolution generated an unstable atmosphere, especially due to these social changes, and provoked the rise of protest movements, of which like Luddism was the major one in the England of the XIX century. Luddites destroyed machines and mechanical tools, making work impossible inside the industries. This sabotage had the purpose of stopping the introduction and spread of machines that replaced manual labour. However, change was taking place, the speed and efficiency of machines showed that human labour alone was no longer sufficient to evolve.
In the short and medium term, the technological revolution worsened the social situation, which saw an improvement only after 1840 when better working conditions, less working hours per day, and higher incomes were established. As a consequence, this change led to a growth in the consumption capacity.
The GDP in England, in those years, reached its peak thanks to the technological and industrial revolution.

Subsequently, new types of innovation began to spread across Europe. At the end of the 19th century the Second Industrial Revolution broke out, which was slowed down only by the First World War.

This phase showed the transformation of the production processes, from a system based on agriculture and crafts to an industry-based system that used mechanical machines with new energetic sources.
It's the revolution that brought the most important contribution, both for technological impact and for the quantity of discoveries brought to, the industrialized, like the introduction of steel, oil, chemicals and, especially, electricity. In this period the role of science became fundamental for technological progress because, differently from the First Industrial Revolution, the Second one saw the discovery of new technological innovations through specialised research in scientific laboratories and universities, funded by entrepreneurs and governments, and not, as before, occasional discoveries due almost entirely to chance. The sectors with the highest result were the agriculture, manufacturing, and food ones.

Industrial development further evolved with the spread of the phenomenon of "industrial gigantism", a phenomenon characterised by the building of big companies where the entrepreneurs could exploit scale economies with the high volumes of production. In these big companies, the processes of Taylorism and Fordism developed; the theory of Taylorism foresaw a scientific method of organization of the work, whose the principles were: the centralisation of authority within the company, the increase of the output of the workers and the income of the company, and the pursuit of science to back up innovations. The fundamental idea of Taylorism was *"one best way"*, the meaning was that inside a company there was just one best, most efficient and profitable way to solve a problem or organize the production of each final output. The theory proposes to divide the work in little controllable phases in order to minimize the wasting time and accelerate the production with a system of repetitive actions that each employee should perform.

One of the most important invention of the Second Industrial Revolution was the combustion engine and all its evolution, that allowed in the earliest years of 1900 the development of the first automotive companies, for which the example of Ford is emblematic. Henry Ford founded the Ford Motor Company in 1903 in Michigan, starting the era of motorised cars in the world. The theory of Taylor was applied in these industries and this phenomenon took the name of its first user, Ford with the Fordism, which brought to the introduction of the assembly line, a process aimed to optimise the work of employees and reduce the time needed to assemble the complex product. With the new system the production of one T Ford, the first car of the Ford Motor Company, passed from 20 hours to an hour and a half. Not initially, but only after redundancies and protests by the workers, the owner of the car industry decided to introduce higher wages and other material incentives for the workers to ensure maximum efficiency during working hours.

Industrialization led to an evident increase in labour productivity, thanks to the technological innovations that brought. First multinational companies were built and in the automotive industry there were the first firms to delocalize: Ford in Great Britain and Fiat (Italian automotive company) in Latin America and Russia.

Moving to transportation, a disruptive innovation was the plane, used for the first commercial flight in 1910, but it became more frequent after the two World Wars. The general improvement of the transport systems, now faster and less expensive, allowed a development in trade.

Furthermore, the invention of electricity brought the spread of lighting in cities and in the houses; in the industries this allowed the shift work system to continue to work at all the 24 hours, therefore overcoming the old system marked by sunrise and sunset. In the field of medicine there were lots of discoveries that helped to learn more about the diseases of the time and to eradicate them, or at least starting to defend against them. Thanks to these studies life expectancy increased enormously and decrease the proportion of maternal and stillbirth deaths. The communication, also, took an extraordinary step forward with the invention of the telephone and radio.

The technological evolution of the Second Industrial Revolution deeply impacted the economic and social system. In 1850, thanks to free trade, not only the price of goods increased, and thus profits for entrepreneurs and subsequent investment, but the living conditions of the working class also improved, as did their average wage.

During the period of expansion, the bourgeoisie gained economic, but also political power, replacing the aristocracy in this area as well. New technologies and innovations grated an increase of real GDP and per-capita GDP demonstrating the positive correlation between technology and GDP, which is a macroeconomic measure of the aggregate value, at market prices, of all final goods and services (i.e. excluding intermediate products) produced on the territory of a country in a given period of time.

Globally, between 1820 to 1950, the per-capita GDP increased by 14 times and the consumption of energy by 7 times. Regarding the industrial methods of working and organization of the jobs, the evolution brought by the Second Industrial Revolution was incredible, as described previously, and this generated the creation of new professional figures like agents, manager, technicians, specialised workers. The creation of new jobs is a natural reply to industrial and economic revolution because of the new needs generated by the new discoveries and technologies.

Katz and Margo presented a study about the Second Industrial Revolution changes occurring in qualified or not qualified jobs, in the period from 1850 to 1910. The qualified workers, called "white collars", grew in the manufacturing industry from 3% to 12% and, in general, in the aggregate economy, from 7% to 20%. In that period, also the amount of not qualified workers increased; there was a shift of the artisans in the industry like qualified workers and a shift of unemployed peasants like not qualified workers in companies. Hereafter, Table 1 shows the exact percentage of these changes in the aggregate economy.

Table 1. Percentage of workers between 1850 to 1910.

	1850	1860	1870	1880	1900	1910
White Collar	**6.9 %**	**8.3 %**	**10.6 %**	**11.6 %**	**17.1 %**	**19.7 %**
Professional-Technical	2.3	2.6	2.9	3.4	4.3	4.6
Manager	3.1	3.6	4.4	4.3	5.7	5.6
Clerical/Sales	1.5	2.1	3.3	3.9	7.2	9.5
Skilled Blue Collar	**11.6**	**11.2**	**10.7**	**9.1**	**11.0**	**11.9**
Operative/Unskilled/Service	**28.7**	**30.1**	**32.4**	**37.7**	**36.4**	**37.9**
Agriculture	**52.7**	**50.5**	**46.4**	**41.6**	**35.3**	**30.5**
Operator/Supervisory	23.9	23.2	24.8	24.8	20.0	16.6
Farm Laborer	28.8	27.3	21.6	16.8	15.5	13.9

Source: KATZ, L.F, MARGO, R.A., 2014. Technical change and the relative demand for skilled labor: The united states in historical perspective, in Bouston L.P., Frydman C., Margo R.A., (Eds.), Human capital in history: The American record, University of Chicago Press, pp. 15-57.

The changes in the working systems let people to improve their life conditions in all the new industrialized countries, but especially in Europe and USA. In this period bourgeoisie established itself as a social class, but the former proletariat had also evolved, partly into the middle class, that began to save money, living in better conditions than in the past.

First Industrial Revolution and Second Industrial Revolution were one after the other, the Third Industrial Revolution, instead, started after more than 30 years from the previous one.

Between the Second and Third Revolution, in fact, the two World Wars happened. During these years of conflicts lots of things changed and the technological tools created were all according to the war's needs.

However, some industries grew up like the automotive one. The big companies, established in the years before the First World War (1914-1918), made possible the spread of cars as means of transport, with an incredible boom especially in the United States.

At the other side, one of the most devastating crises happened in 1929, the Great Depression. The lack of growth in purchasing power despite increased productivity and investment, the Fed's monetary policy and the continued expansion of credit through artificially low rates and excessive speculative lending are considered to be among the main causes of the crisis that culminated in the Wall Street crash (-43%).

The consequences were important: industries of durable goods of consumption had to drop out orders to their suppliers, reduce wages to workers and fire employees. People ran to take their savings from the banks and the market went through a liquidity crisis, generating the failure of different banks and, consequently, the failure of companies which has invested on them. The industrial production decreased of 50% and failures and consumptions contributed to feed the crisis.

A little recovery was in 1933 with the election of American President Roosevelt, who planned a program of social and economic reforms, it was the New Deal; but the Dow Jones index retrieved the levels pre-crisis only in 1954.

The Second World War (1939-1945) caused another period of deep regression for people, companies and governments. Every company in different industries, if possible, changed their production according to the conflict. In September 1945 the conflict was finally over and the following years was defined by a recovery phase, economic and political expansion of the industrialized countries and technological progress. The real recovery from the war was in the period called Third Industrial Revolution, which lasted from 1950 to 2008.

Some researchers believe that this revolution is currently in progress, but for the multiple differences between the improvements of the period after the war and the technological changes of the recent years it's common to define a distinction between these two periods. This difference will be further explained later with more details, distinguishing between the Third Industrial Revolution and Industry 4.0.

The Third Industrial Revolution was characterized by the incremental advancements of more sectors; first of all, the agricultural one, with an increase in the production. Productivity growth was due to the use of synthetic fertilisers, heavy insecticides, new irrigation methods, tractors and other agricultural new irrigation methods, tractors and other agricultural vehicles with internal combustion engines, in fact agricultural modernisation. With policies to sustain prices the sector could grow without losses.

The industry sector resumed work and growth with increasing investment and new projects, with a positive and proactive outlook compared to the previous period of repression.

In the chemical field, a big improvement was the use of chemical fibres (synthetic and artificial) to supplant natural ones. The production and use of the plastic in more objects and tools began to boost new industries and sectors.

In the demographic point of view, there was a huge increase of world population. Average life expectancy had risen sharply from 50 years in the early 1900s to 65 years in the immediate post-war period (second). The average age has risen to 80 years in the industrialised countries in the following years, and population growth has been impressive especially in Africa, China and India, from just over two billion people in the post-war period, today the population is over seven billion and still growing, but only on the African continent. Demographic development has been possible thanks to ever lower infant mortality and strong medical and pharmaceutical progress (surgery, antibiotics, vaccines). The trade developed between countries and the globalization began to put their basis for the following evolution.

The Third Industrial Revolution saw the growth of the tertiary sector, with the spread of services: health, education, distribution, transport, public and private services, banking and insurance systems, IT and telecommunications. During this phase, the information society was created, three key sectors were born for the entire subsequent growth period: electronics, telematics, and information technology. In this period was invented: mobile radio, television, CD, PC, mobile phone, containing microprocessors, which could only operate if guided by a programming language. The XX century electronics is digital, no longer analogue like that of the Second Industrial Revolution.

Telematics deals with the transmission of information at a distance, i.e. the use of technology in telecommunications and media, and the connection of technologies via networks (cables, satellites, fibre optics) over which a very large amount of data can pass. Information technology deals with the processing of information, the study of information, using automated procedures. It is closely linked to telematics and electronics and with them forms ICT (Information Communications Technology), i.e.: formation, processing, transfer, processing of data and information.

The oil shocks of the shocks of the 1970s undermined the Fordist model. The Western world realised this when in the USA, the Japanese Toyota compact car model outsold the major American car manufacturers. Toyotism was based on streamlining, multifunctional working cooperation, just-in-time production and industrial elasticity. During the 1980s, therefore, we moved on to the Post-Fordism model, which took its cue from the Japanese model. In this model, a fundamental role was played by new technologies that were to allow: lower energy consumption, greater flexibility (programmable automation) and decentralised production. Important impulses to post-Fordism came from economic globalisation (and speed in transport), and from the process of privatisation brought about by post-crisis neo-liberalism, where state intervention, contrary to previous periods, was decreasing more and more.

The aim was to make obsolete the durable goods people already owned, thus making technological product innovation central. There was a shift from mass production to lean production. Post-Fordist industries, however, reduced labour costs by lowering wages (for unskilled workers) and cutting staff, thus creating more unemployment. This also explains the increase in skilled workers compared to those without specific skills.

Looking to the pro-capita GDP in the world, its growth was extraordinary in this period than in the past. In 1820, Europe's GDP per capita was three times that of Africa, while in 2008 it was thirteen times that of the 'dark continent'. Even more expressive is the fact that 15% of the population in high-income countries hold 80% of the world's GDP, also highlighting a difference within Western states themselves.

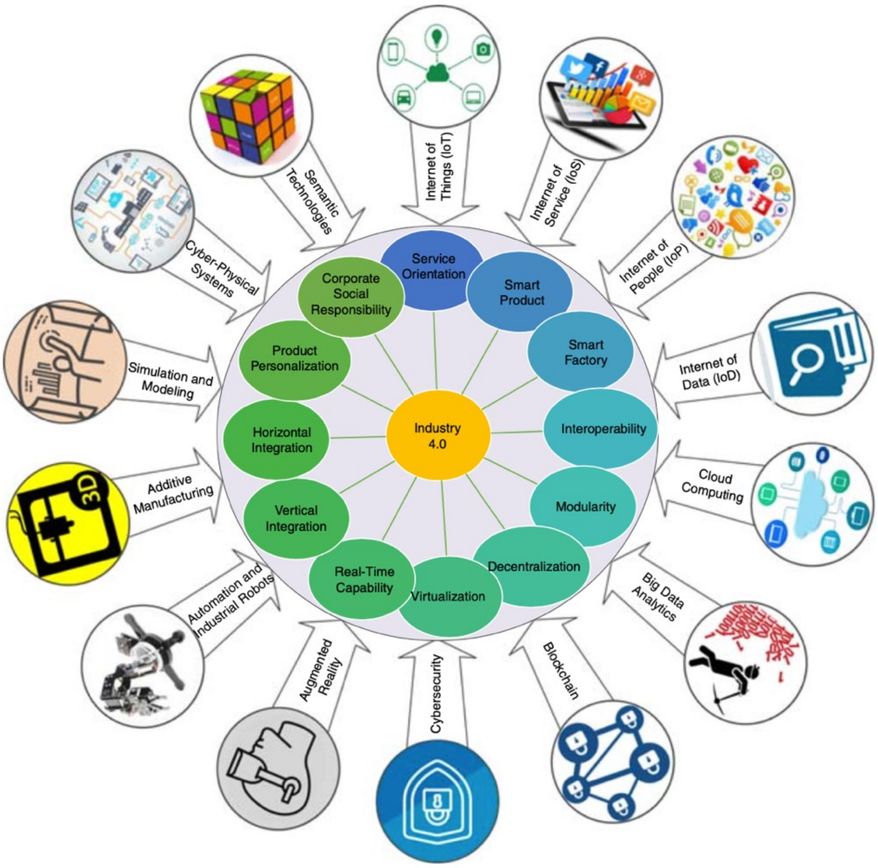
In summary, the quality of life since 1950 has certainly improved in Western countries. New technologies have enabled an easier everyday life, and fewer working hours than in the past for workers. The 1970s also saw the creation of the labour statute, which allowed freedom of opinion and protection of workers' freedom and health, as well as the freedom to join trade unions to protect working conditions. Life expectancy has increased significantly, as have the opportunities for education and high salaries for skilled workers. In addition, hygiene, health care and services in urban centres have improved. The modern economy has helped to create an upper middle class that is more dominant than in the past, but it has also increased the differences between the rich and the poor. Post-Fordism, however, with its tendency towards delocalisation and de-industrialisation, has led to higher unemployment in Western countries than in previous periods.

The Fourth Industrial Revolution (with the concept of Industry 4.0) or, for some researchers, the second phase of the Third Industrial Revolution, began recently, after the crisis of 2008, and it's already in progress. There are three elements that make this period, effectively, a new revolution, which are: velocity, scope, and system impact. In addition, one disruptive innovation that impacted extraordinary the world was the digital revolution, which characterize this phase.

Steven Covey wrote that from the First Industrial Revolution to 1950 manual workers produced most goods and services with their body, but in the last fifty years, knowledge workers produce most goods and services with their minds. They provide creativity, focus and innovation mind-set able to improve the efficiency of the companies. The challenge began how companies can motivate knowledge people to perform their best potential.

The fundamental innovations of the Fourth Industrial Revolution are: 3D print, augmented reality, virtual reality, artificial intelligence and IoT systems. The main technological developments are related, especially, to the introduction of IoT in almost every aspect of life. IoT (Internet of Things) uses internet and the web connections for making smart and intelligent some common objects used daily by everyone, bringing them in the digital world. This process, which is still evolving, contributed to the creation of the smart car, smart cities, smart home, smart metering and, also, smart industries. This last application, especially, is related with what it's called Industry 4.0, which is the current propensity to use industrial automation and new technologies in order to create new business models, improve the working conditions, increase the productivity of machines and improve the quality of products.

Figure 1. Design principles and technologies of Industry 4.0.



Source: GHOBAKHLOO, M., 2018. *The future of manufacturing industry: a strategic roadmap toward Industry 4.0,* Journal of Manufacturing Technology Management, Vol.29, No. 6, pp. 910-936. DOI: https://doi.org/10.1108/JMTM-02-2018-0057

The term Industry 4.0 was firstly used during an exposition in Hannover where Henning Kagermann, Wolf-Dieter Lukas and Wolfgang Wahlster explained this kind of evolved industry that, through new investments, could develop a better infrastructure system, introduce energy sources improvements, finance university and research entities in order to improve the manufacturing sector and make it competitive globally. Industry 4.0 is related with the concept of "smart factory". A smart factory follows the idea of decentralized production system that work through different processes connected in real time, allowing a better interconnection between machines, devices, people, and human resources and improve synchronization between the phases of work. This mechanism evolved in the idea of digital supply-chain, where all the parts of the chain are connected centrally, giving always a current and accurate perspective of production processes.

The IoT applications typically generates a big amount of data, that are analysed and used to improve and better organize the process; for the storing are used infrastructure like cloud platform in order to have all the information in one place always available, not as in the past where everything was printed, and the analysis was really superficial. It's let company have a continuous information flow that can be used to improve production process or the management system or just to control and know the firm situation.

In addition, the application of artificial intelligence allows to program some actions and teach to the robot how act by itself, transforming the traditional industrial robot, intended as automized arm, in a Smart Manufacturing Robot able to locate a problem and solve it. For example, if a machine is programmed to predict and take under control its internal mechanisms can be able to warn if it's needed to maintenance or repair the worn part until the machine breaks.

These new innovations introduced in the Fourth Industrial Revolution describes a world where individuals move between digital domains and offline reality with the use of connected technology to enable and manage their lives. People can't control the evolution of these new technologies and the disruption that they brought but can be predicted some opportunities and challenges deriving from their introduction. Min Xu, Jeanne M. David and Suk Hi Kim (2018) explain that one of the main opportunity is to lower barriers between inventors and markets due to technologies like the 3D print for prototyping reducing the traditional time required to produce a prototype; secondly, the improvement of artificial intelligence generates threats for different kinds of employment but, at the same time, gives the opportunity to create new innovative jobs.

The integration between scientific and technical disciplines, moreover, can create new fusions of technologies able to create new markets and new opportunities of growth for each element of the blending. This idea makes interacting different fields in the perspective of creating new innovative products or services.

Furthermore, technologies are still changing the people life; robots, nowadays, are able to cook, play music, record shows and drive cars and in the near future there will be the possibility to customise them letting people to focus on what they really like to do.

Another application is the Internetworking of physical devices. The introduction of IoT goes in the direction of the previous idea. With the internet connections the objects became digital but interconnecting in a net more objects the applications multiply.

Martinelli, Mina and Moggi (2021) analysed in-depth technologies of the Industry 4.0. They believe that this era has not yet the characteristics to be called Fourth Industrial Revolution because of the still limited scale and scope effects, but it's more appropriate to consider it as the fundamentals of a future revolution. In their analysis the scholars examine, in particular, Internet of Things (IoT), Big Data, cloud, robotics, artificial intelligence and additive manufacturing, also known as 3D printing and tried to understand if those technologies can be considered as general-purpose technologies (GPTs). A GPTs technology is characterized by pervasiveness, meaning that it has a broad range of possible application in different sectors, high technological dynamism, with potential for increasing efficiency and the ability to generate complementarities, that is able to boost the technical progress in the application sectors. The scholars tried to classify the innovations and understand if they can be considered as GPTs using the Industry 4.0 patents and capturing the identifying characteristics through:

- Generality index: indicates the range of later generations of inventions that have been promoted by a patent, those classes that cite a patent.
- Originality index: captures the backward patent citations, the technological classes cited by a patent.
- Longevity index: measures the speed of obsolescence of a specific patent.

Using these three indicators to compare technologies and to characterize them as general-purpose technologies (GPTs), the study reported as result that only Big Data represent a statistically significant innovation in terms of generality, originality and longevity. The other technologies, for the moment, doesn't demonstrate this tendency.

The introduction and the spread of these technologies is a phenomenon that is already in progress, the full transition and evolution of this sectors and their impact is not still evident and effective.

The most relevant challenges, deriving from this technological revolution, are related to job displacement, cybersecurity, hacking, risk assessment. These are important problem to take under control and to try to solve before they happen. But, for doing this, it's necessary the introduction of controlling system able to protect the interconnected devices in order to reduce the risk.

1.2 - INDUSTRIAL ROBOTICS OF XXI CENTURY

The insertion of industrial automation in companies, globally, has started from the most industrialized countries, especially China, India, USA and Europe. The process, typically, has seen before the introduction of ICT (Information and Communication Technologies) which let companies become digital and create the needed connections in order to structure a net of information, and just in a second moment the entry of industrial robots.

A little disclaimer about industrial robots analysed in this work because there are different typologies of robots evolved through the years. Here are described the characteristics and impact of robots that work inside factories and are involved in the supply chain systems, not those who are used for services or other applications outside the industrial context.

The first industrial robot was invented in 1961 by George Devol and inserted in the General Motors factory of Ewing (New Jersey). "Unimate", as the robot was known, was able to handle die-cast parts taken from a line and welded into car bodies. This operation was risky for employees, cause of the toxic fumes and physical damages that could origin. It was part of the first generation of robots, which were programmed for executing sequential repetitive actions independent from the human intervention.

The second generation of robot was composed by machines able to understand the external environment, choose the best strategy to adopt in every specific situation and to manage problems and disorders that can happen during the operation.

Finally, there is a third generation of robots, where the machines use the artificial intelligence during their operations. This kind of robot can verify, manage, work and analysed problems and working processes by its own creating new algorithms based on the situation. In this script this is the category considered for describing the current situation and penetration of robotization into companies.

Moreover, there is another distinction into the robots' third generation category, between the autonomous industrial robots and the collaborative ones, also called "Cobots". The Cobots are specialized collaborative industrial robots, which are used in the supply chain in cooperation with the human work. Generally, to these robots are assigned repetitive operations that can damage the employee that, with this contribution, can work on more specific phases of the process. They are easily programmable, flexible and versatile because they can be re-programmed infinite times. The Cobots, in addition, have helped to reduce the costs of production and increase the company's productivity.

The autonomous industrial robots, as the name suggests, are machines that work autonomously, typically are inserted into cages for safety. This kind of robot is usually related to the mass production.

The distinction just explained is relevant for the analysis and the discussion of the next chapters because the third-generation industrial robots need not just to be programmed and be positioned in the workplace for the operations, but they need to be connected through internet. This is possible just in companies with a digital environment already present.

The digital transformation in companies is a process still in progress and the transition depends on the presence of infrastructures in countries, the presence of speed and broadband internet connections and the operative companies' actions that allow the effective transition arranging the supply chain or the offices with the right instruments.

Scholars started to speak about digital transformation since the first years of 2000 when Internet, computers and the information technologies developed in the '80s and '90s began to spread within companies. The effective transition is considered the passage from the analogic mechanics and electronics to the digital ones.

In the world as reported by OECD[2], digital technologies were adopted firstly by USA and EU North countries, followed by China and India, which were developing countries in those times. The 2017 OECD report described the percentage of companies' investments in R&D: China was at the first position with the 75% of expenditure, Korea invested the 53%, Israel the 45% and 35% the United States. The high percentage of investment in R&D in the last years by countries like China, India, Korea, Israel, nowadays, demonstrated their advantages in the digital and information fields.

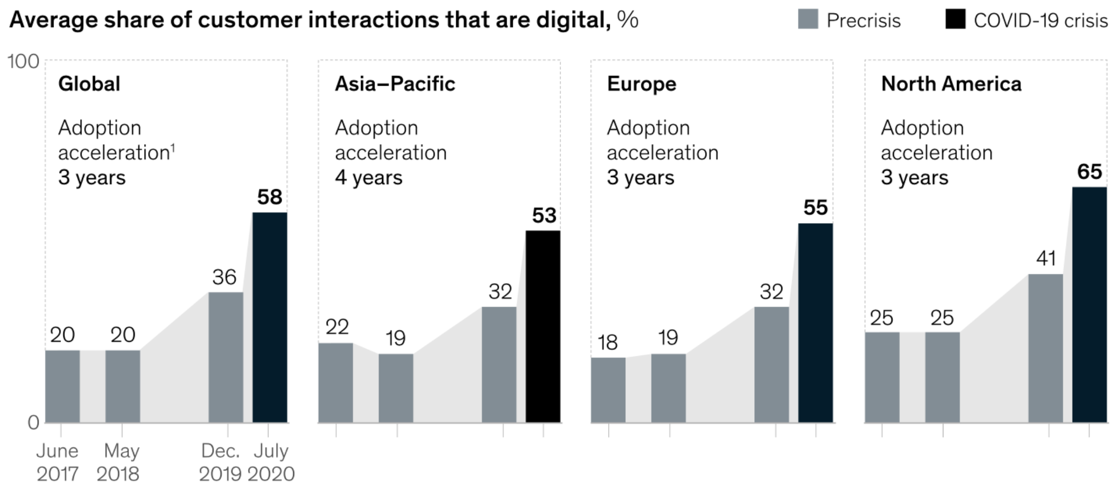
Moreover, the pandemic situation caused by Covid 2019 has boosted the digital transformation, and how reported by the OECD Digital Economy Outlook 2020 has raise the digital presence of the 70% of worldwide SMEs[3]. In fact, the impact of the virus was especially on small and medium companies because the multinational firms or big structured companies have already adopted those tools in order to continue to compete and/or remain the top leaders in the market. In several countries, instead, SMEs have not yet faced this transition or they have to only partially and the pandemic, that has blocked workers and customers at home, incentivized the

[2] OECD: Organization for Economic Co-operation and Development. It's an intergovernmental economic organisation with 38, developed and developing, member countries founded in 1961 to stimulate economic progress and world trade. Source: https://www.oecd.org
[3] SMEs: small and medium-sized enterprises.

utilization of digitalization, both creating a space for the interconnections between workers and implementing e-commerce or customer service in order to continue to sale.

Across regions, there was a seven-year increase, on average, in the rate at which companies are developing these products and services. In the Figure 2 is represented the percentage of adoption of digital solutions before Covid-19 and after its spread.

Figure 2. Percentage of adoption of digital solutions for customers.



Source: LABERGE, L., ET AL., 2020. *How COVID-19 has pushed companies over the technology tipping point – and transformed business forever*, McKinsey & Company.

Industrial robotization is the linear follower of digitalization. The first required the presence of digital tools, especially in the concept of Industry 4.0.

Robotics technology, from 1990 to 2000s, developed a lot. As described in the International Federation of Robotics (IFR) Report of 2020, the total amount of robots in the world is around 3 million in the manufacturing line. In the last five years, from 2015 to 2020, the growth index was annually on average of 9%.

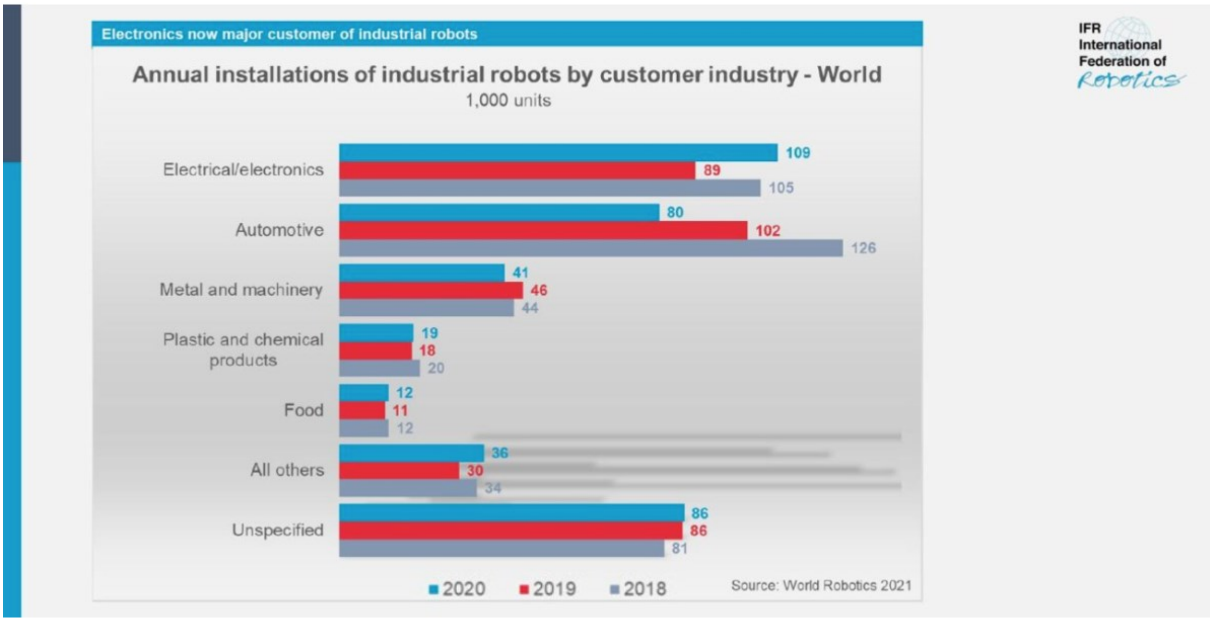
The main adopters were in USA and Western Europe with an increase in the number of industrial robots between 1993 to 2007. In the United States the analysis reported that the new installation was of 1 robot for 1000 workers, instead in the Western Europe 1.6 new installations per 1000 workers. In the last few years, instead, was China and Asian countries that have contributed majorly, with an increase of 6% of new installations in 2020 from the previous year, while United States and Europe decreased their respective growth trend. China installed, in 2020, 168.000 units, almost the half of the total sales and 71% of the total new robots' installations, followed by Japan (38.700) and USA (30.800), Korea (30.500), Germany (22.300) and Italy (8.500).

The average density of robots is increased of 12% in the last year, which is the number of installed robots per 10.000 workers. In this classification the population density of each country determines different results from the previous ranking. Korea ranks first with 932 units per 10.000 workers, one robot every ten humans. The global mean is 126 robots per 10.000 workers and Italy has an amount of 224 machines.

In all the past years from the introduction of robots, the sector most involved in the robotization transition was the automotive industry, which utilized 38% of existing robots in 2019, following by the electronics industry with 15%, the plastic and chemicals industry which used the 10% of robots and the metal products industry with 7%.

The analysis of 2020 of the IFR reported, instead, a turning point in this trend with higher new installation numbers in the field of electronics with 28,4% robots. The automotive industry uses 20% of robots. In the following Figure 3 is represented the division between sectors.

Figure 3. Annual installations of industrial robots by customer industry – World



Source: World Robotics 2021.

The phenomena of “cobots”, the collaborative robots, is increasing in the last three years, from 2017 where the installed base was almost of 2%, in 2020 the new installation were the 6% with 22.000 units compared to the 362.000 units of industrial robots. The data are not so impressive, but relevant because in 3 years they doubled and the forward trend is an incremental index of almost 30% new installations of cobots in 2030.

CHAPTER 2 – AUTOMATION AND EMPLOYMENT

2.1 – ROBOTIZATION IMPACT ON EMPLOYMENT AND WORKERS' WAGES

The introduction of industrial robots in companies and factories determined the development of important discussion, especially regarding the employment issue. Schumpeter in 1942 suggested the concept of disruptive innovation to indicate the capacity of technology and innovation of destroying workplaces, companies and entirely sectors, but also, at the other side, boost employment, new jobs, new firms and new sectors.

There are two relevant strands of thought, those who believe and sustain that robotization reduces the human work and makes companies hire employees, and, at the other side, those who think that the evolution of automation and the insertion of robots in factories and supply chains will bring to the creation of new jobs, new skills and new capabilities, creating a complementary environment between worker and robot. A change in employment or unemployment levels caused by technological innovations and digital transition is inevitable but going deeply into the dynamics of change the scholars found different results.

Initially, the studies focus on understanding which are the main factors impacted by technological transition, detecting firstly the educational level to discriminate the jobs that have more possibilities to be replaced by machines. On this research, the investments on innovation increase the productivity of qualified work, which is related to the higher educational level respect to the unqualified work, increasing the wage and the salary inequality.

Autor et al., in a paper of 2003, reported that a better relationship in order to understand the impact of machines was between technological innovations and job typologies, instead of the educational level. Following this idea Acemoglu and Autor (2011) suggested a job classification in order to highlight the characteristics of the work, not the skills of the worker.

The distinction was between:

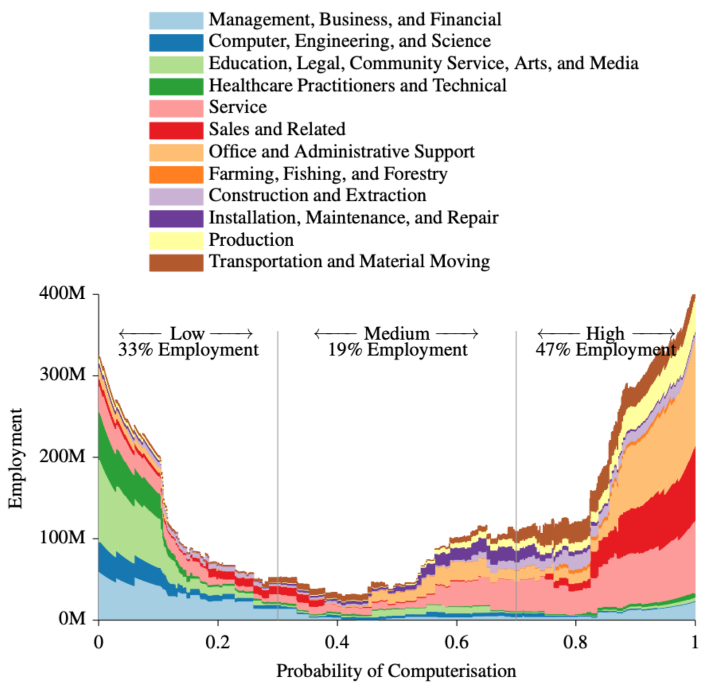
- Analytical and interactive non-routine tasks
- Analytical and interactive routine tasks
- Manual routine tasks
- Manual non-routine tasks

The study demonstrated that automation is more adaptable to substitute routine jobs, both manual and cognitive, instead it's most difficult for machines to substitute non-routine tasks. The result was an increasing of highly qualified or low qualified job requests and a reduction of medium qualified job positions, which will be substituted by robots. This conclusion gives credit to the Autor et al. (2003) hypothesis, that the technological progress shifts the work demand on non-routine jobs.

If the considering characteristic is the output of the production process, Van Reenen (1997) described that the automation can lead to a negative effect because the introduction of machines implies that labour input per unit of output decreases, labour productivity increases, which implies a lower employment level. On the other point of view, automation may also reduce the marginal cost of production, which, in turn, gives rise to a higher output level. This expansion will increase employment.

Moreover, Frey and Osborne (2013) documented how technological transition negatively impacted the employment. In the analysis they considered the probability of computerisation of 702 detailed occupations distinguishing them in high, medium and low risk occupations. The result was that around 47% of total US employment is in the high risk category, describing that they can be potentially automated in the one or two decades.

Figure 4. Employment affected by computerisation.



Source: FREY, C., OSBORNE, M. 2013. *The future of employment: How susceptible are jobs to computerisation?,* Technological Forecasting and Social Change, Elsevier, Vol. 114(C), pp. 254-280. DOI: 10.1016/j.techfore.2016.08.019

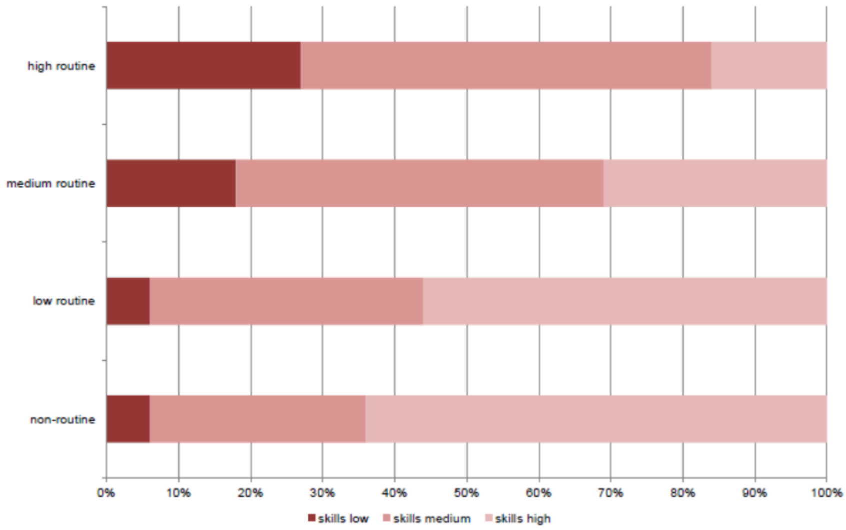
In the Figure 4 it's presented a graph of the different categories of job impacted by computerisation. As it's shown, management, business and financial category, computer, engineering and science category, educational, legal, community service, arts and media category and healthcare category are less impacted by the computerisation with a low risk of be substituted; at the other side, especially the service category, sales category, office and administrative category are considered more at risk to be negatively impacted, and this last result is worrying because almost an half of the total US employment is involved in the high risk category jobs. The US Council of Economic Advisers ranked occupations analysed in this paper by wages per hour. The findings revealed that 83 percent of jobs making less than $20 per hour and they would come under pressure from automation, 31 percent of jobs making between $20 and $40 per hour and 4 percent of jobs making above $40 per hour. The study, at the end, suggested that workers for win the race over the technological transition will have to acquire more creative and social intelligence and perception and manipulation tasks.

Similar research was done by Bowles (2014), who investigated the automation impact on the EU area. The results were that the ICT will make lose around 47% of jobs in North Europe countries like Sweden, which are also the most developed countries in that zone, and around 60% of job losses in East countries like Romania.

About the wages level in US and Europe, they are affected, to one side, by robotization and introduction of automation in factories, to the other, they depend on educational level of employees and skills of human resources. First of all, the wages of non-college educated males decreased between 1979 and 2012. Secondly, full-time weekly earnings of male high school graduates fell by 15 percent and those of male high school dropouts fell by 25 percent. The ratio of male employment to population in the group 25-39 years old has fallen with low and decreasing earnings. Those data, in addition with the simultaneous incrementation of technological transition level, revealed a decrease of the demand for less skilled workers.

The main critic on these studies, however, was by Arntz, Gregory and Zierahn (2016) because of their occupational-based approach, the jobs were analysed looking to the current occupations, not looking to the tasks categories. And for the scholars this overestimated the results. They proposed an analysis where the impact was determined on the task-based approach, allowing to analyse different daily activities in the same occupation. This let them find that the substitution percentage of jobs was lower. They analysed the risk of automation in 21 OECD (Organization for Economic Cooperation and Development) countries, selected in relation to the PIACC (Programme for the International Assessment of Adult Competencies) database, proposing a new classification of routine and non-routine tasks based on individual answers of an investigation about the capabilities of workers. This work demonstrated that the routine-intensive tasks decreased with higher skill-level and the jobs where the skills requested were lower were more routine-intensive. The jobs with a medium routine intensity are usually the ones medium qualified, like it's represented in Figure 5.

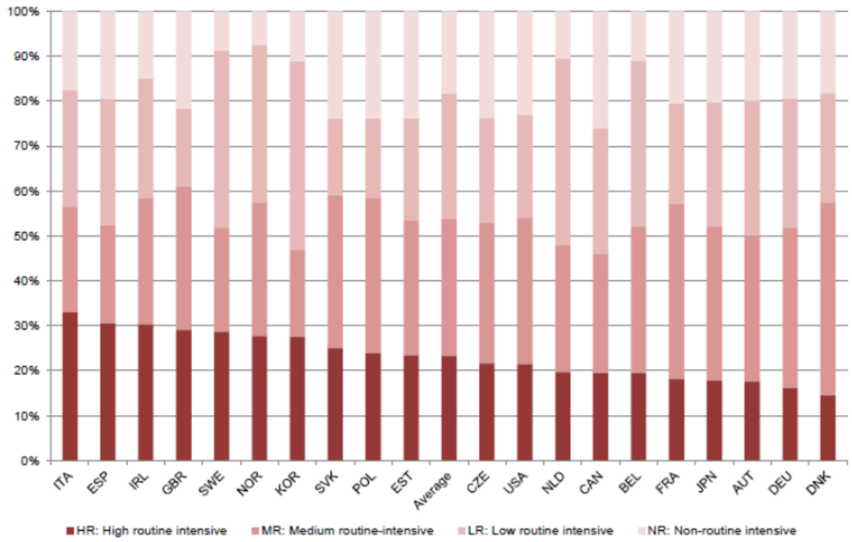
Figure 5. Employment by skills and routine intensity



Source: MARCOLIN, L., ET AL. 2016. *Routine jobs, employment and technological innovation in global value chains*, OECD Science, Technology and Industry Working Papers, OECD Publishing, Paris. DOI: 10.1787/5jm5dcz2d26j-en

The research reported that around 73% of people, in the OECD area, work in high routine-intensive jobs and the 68% of the medium routine-intensive jobs are related with medium skills level. These are all jobs highly imputed to be substitutes by automation systems, the analysis reported that 14% of jobs will surely be replaced. This means 66 million people of 32 countries. The 46% of people, instead, work on non-routine or low routine-intensive jobs. Also, this research described the countries that are most impacted by the technological innovation because of the major presence of highly routine-intensive jobs (Figure 6), finding that South Europe countries, like South Italy and Spain, can be more automatized; at the other side, Denmark, Austria and Germany present lower percentage of routine-intensive jobs. Aggregating, instead, high routine-intensive jobs and medium skills-level jobs, the resulting countries are United Kingdom, Slovakia, Ireland and Poland.

Figure 6. Employment by routine intensity in OECD countries (2011-2012)



Source: MARCOLIN, L., ET AL. 2016. *Routine jobs, employment and technological innovation in global value chains*, OECD Science, Technology and Industry Working Papers, OECD Publishing, Paris. DOI: 10.1787/5jm5dcz2d26j-en

The same point of view was presented by Ford (2009, 2015), who affirmed that machines will substitute more jobs than the creation of new occupations will be able to cover. Moreover, he believed that the speed of change caused by the automation and the introduction of ICT is faster than in the past. The first job to be replaced are the routine-intensive jobs or the ones where the skills required were low, but in the last years, also the more cognitive and non-routine jobs are subjected to the automation impact, because the last generation of robots is able to reply to problems and act autonomously thanks to the artificial intelligence. In fact, if a job has the routine characteristic or can be forecasted in its operations, the possibility to be reproduced by a robot is really high, it's needed just an algorithm to program in the machine.

At the other side, one study of the McKinsey Global Institute (2017) on 46 countries, that cover the 80% of total employment in the world, demonstrated that less than 5% of the jobs can be totally automatised and the 60% of jobs can be automatised for the 30%.

Scholars agree that manual labour will be revolutionised by the technologies, and it won't be imagined in the same way as today. (Brynjolfsson and McAfee, 2015)

In a more recent study Acemoglu and Restrepo (2017) showed that one more robot per thousand workers negatively affects the US employment-to-population ration by 0.37 percentage points, with losses approximately from 360,000 to 670,000, and Chiacchio, Petropoulos and Pichler (2018) found around 0.16-0.20 percentage points in EU. This last study, in addition, reported that the wages growth is negatively impacted by automation.

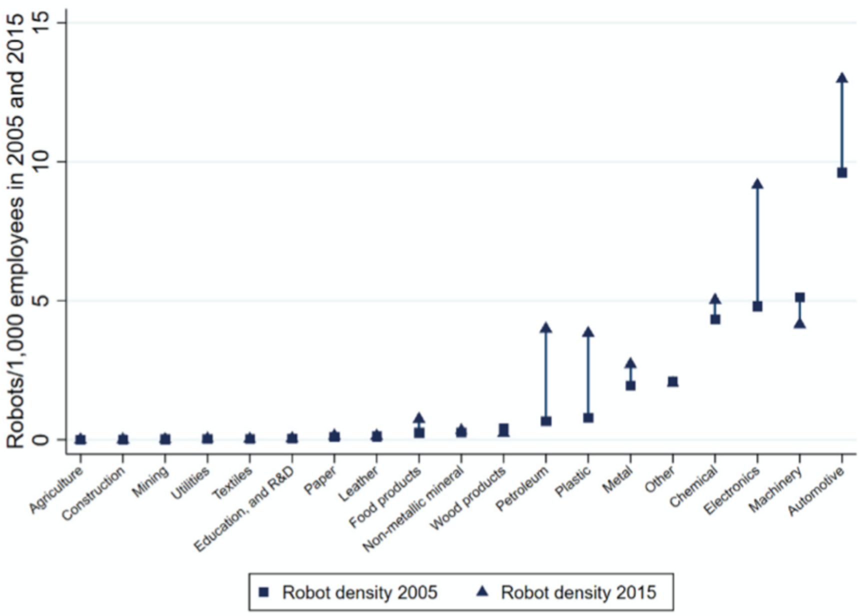
Looking, instead, emerging countries, Carbonero, Ernst and Weber (2020) presented a study about the impact of robotization in those economies, demonstrating the negative impact of machines on employment. This result was quite logical because in emerging countries the labour costs is low, surely less than implementing companies with automatized machines, and the infrastructure systems required for introducing those robots are not developed as it's needed. They estimate that, if companies in those countries will be implemented with robotization the resulting unemployment level will range from 55% in Uzbekistan to 85% in Ethiopia. The study of Schlogl and Sumner, moreover, reported that wages in emerging countries may stagnate due to the introduction of robotization and higher level of unemployment. A McKinsey report (2017) suggests to use and exploit this emerging countries like Indonesia, Mexico, Nigeria, Saudi Arabia, Turkey, because, with right policies and conscious introduction of automation they could incentivize the economics and increase the GDP.

These catastrophic studies which explain the negative impact of technological innovation on employment present some limitation because they don't take into consideration the transformative action on sectors, that will evolve and develop with the technologies and can create a new environment for workers and their capabilities.

A study made by J. de Vries et al. (2020) reported how the increase of robots impact the employment analysing 19 industries in 37 high-income and EMTEs[4] from 2005-2015. This research is relevant because looked specifically the which sectors are more involved in the robotic transition. In the Figure 7 is represented the industries considered and the robotization levels from 2005 to 2015.

[4] EMTEs: Emerging Market and Transition Economies.

Figure 7. Increase of industrial robots from 2005 (square) to 2015 (triangle).



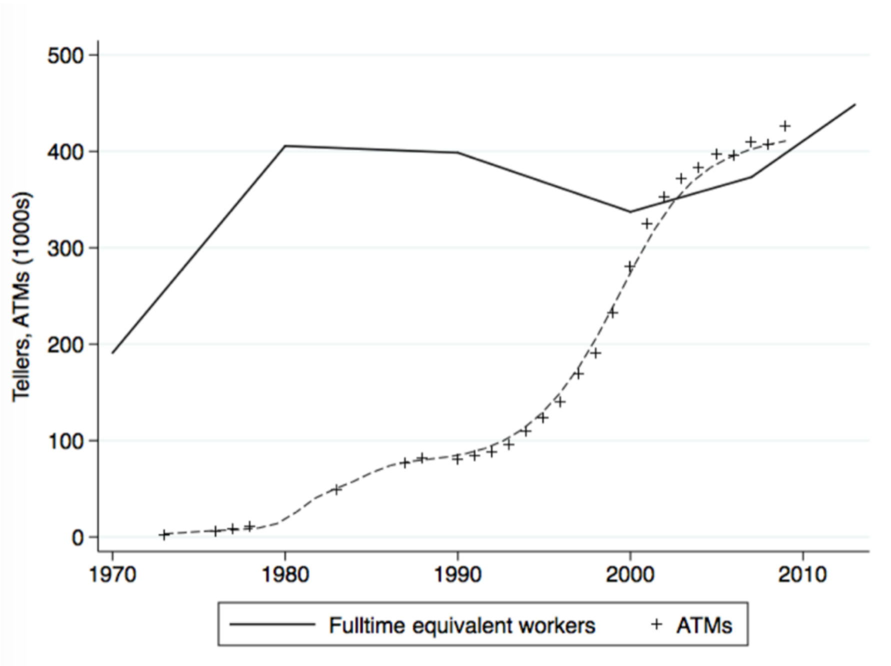
Source: DE VRIES, G.J, ET AL., 2020. The rise of robots and the fall of routine jobs, Labour Economics, Vol. 66. DOI: https://doi.org/10.1016/j.labeco.2020.101885.

The findings explain that it's expected a positive change in employment share of non-routine jobs and negative changes in the share of routine manual jobs. Furthermore, these relations are significant high-income countries but, in emerging countries and transition economies these correlations are not present, probably because the human manual jobs are still more convenient and price-competitive in the market.

Being in this moment, inside the process of transition, the results are not clear and the hypothesis different, the same World Economic Forum Report changed its perspective from 2016 to 2018, from a really bad employment forecast due to automation to a more positive prevision, describing how artificial intelligence and advanced robotics will create 133 million workplaces respect to the 75 million destroyed.

A different point of view is reported in the research of Bessen (2019), who argued that the key to understand the changing employment is looking to the nature of demand. The scholar used historical data over two centuries in the textile, steel and automotive sectors in US. His inverted U-shape model represented the following result: if demand increases sufficiently in response to productivity-improving technology, the employment will grow; otherwise, it will fall. One reason of the growth of demand in response of new technologies is related to the reduction of prices in competitive markets because of the new introduced robots. During the early years, as it's explained in the theorical model, there were large unmet needs, so the price reduction brought by productivity-improving technology spurred strong demand growth. Demand grew faster than labour productivity, resulting in increased employment. Later, however, demand was satiated; ongoing automation still reduced prices, but these reductions did little to spur demand, resulting in job losses. The empirical model demonstrated that new technologies for a century or more caused a boost in employment, but then the market was almost saturated, and the job losses increased. It doesn't necessarily cause mass unemployment but generate a need for mass worker reallocation between shrinking sectors and growing sectors. Bessen, in addition reported as example in Figure 8, the ATM system, that should substitute hundreds of American counters, but the result was that from the introduction of ATM in 1970 to 2012-2013, the number of counters is doubled.

Figure 8. Number of ATM and counters between 1970-2013



Source: BESSEN, J., 2015. *How Computer Automation Affects Occupations: Technology, Jobs and Skills.*

Moreover, in Germany, which is the European and the second in the world most robotized country, the robotic exposure determines a displacement effect in manufacturing, but fully offset by the creation of new jobs in services. The research of Dauth et al. (2021) analysed how workers and firms adjust to reply to the automation exposure. The findings show the presence of considerable displacement and re-allocation effects. These effects in manufacturing impact mostly the young workers because of the low experience, but the re-allocation in service sector is directly correlated and allows them to be employed. The young workers can, in addition, change and adapt their educational choices in relation to the automation transition that occurred. Instead, the incumbent takes advantages changing roles inside the same firm, after the introduction of robots. Moreover, the indicators demonstrate that those new jobs within the same company are of higher quality and pay higher wages.

Following this research, Dottori (2021) made a study for Italy (second European economy for robot stock) both at the worker level and at the local labour market level for the period 1990-2016. As resulted also in the previous paper made for Germany, local employment is not negatively affected by robotization in Italy, just a little evidence has been observed for manufacturing sector. Looking to the worker, the study reported that the incumbent employees are not negatively affected on average by the increase of robots and, in addition, the higher level of output in companies translates in higher earnings and, consequently, higher average wages for workers. Moreover, automatized machines exposure contributes to the reshaping of sectoral distribution of the new labour force.

Always about Italy, another study of Cirillo et al. (2020) analysed effects of Industry 4.0 on employment and management systems of companies. In this research the focus was not just on automation, but also on digitalisation and interconnection. The findings explain that in Italy is not still possible to speak about a real transition toward Industry 4.0, in the sense of smart and agile company able to interconnect machines, devices, people, and human resources. From the study rises that the major effort in companies was directed to the implementation of production planning software and cyber-security, rather than robotics in the optics of the achievement of better lean production systems. Investigating the technological transformation of three high-tech automotive companies in Italy, which are Ducati, Lamborghini and Cesab-Toyota[5], the main empirical findings demonstrates that digitalisation and interconnections are more advanced than automation. In the organization management, changes after the introduction of those technological systems determine a general intensification of working rhythms for employees, some human management innovations like the introduction of Team Leaders which coordinate and coach the team and the resources within it, more flexibility due to job rotation systems and a better communication and monitoring systems able to control and manage production process and to highlight bottlenecks.

[5] Cesab-Toyota: subsisiary of the Toyota group since 2001.

In general, however, the results are relative to the samples took in consideration in each study. In the paper of Bekhtiar, Bittschi and Sellner (2021), the scholars sustain that the choice of industries included in the sample highly influence the effects of robotization on different outcomes. The analysis compares two different samples, one containing all available country-industry observations from IFR data and the other one containing only country-industry observations that are affected by robotization. The main findings demonstrate that excluding non-robotizing industries there is, first of all, significant reduction of productivity effects of robotization in the period 1993-2007 and the effect on prices were no longer significant in the robotizing sectors. For employment the results changed too from a reduction of occupation in the full sample to an insignificant effect in the reduced one. Those deductions are important because the right elaboration of data brings to effective and real findings and the interpretation process influences the results.

2.2 – INFLUENCING FACTORS IN AUTOMATION AND EMPLOYMENT SCENARIO

The opposite perspectives reported in the previous chapter represent the different potential situations that can evolve in the near future and report valid explanations of the resulting outcome, demonstrating also the ambiguity of the conclusions.

For understanding the effective impact of robotization on employment it's fundamental to step back and consider these two topics distinctly because, robotization processes and automation extension, like also, employment growth or reduction are influenced by different factors. Taking these two aspects separately, it helps to understand how the final positive or negative correlation between automation and occupational levels is determined.

Firstly, as reported by McKinsey (2017), there are five factors that influence extension and speed of robotization:

- Technical feasibility
- Cost of developing automation technologies
- Labour market dynamics
- Economic benefits
- Regulatory and social acceptance

Technical feasibility, or technological development (the invention of new technology), represents integration and adaptability for the specific activities with which they should be replaced. The relationship between technical feasibility and effective implementation is important, meaning the capacity to produce in the company using the new technology. In fact, between these two elements there is a period, more or less extended, until they will be able to coincide.

The second factor is the cost of developing automation technologies. Development of these tools requires hardware (moving parts, wheels, sensors) and software (virtual) components. Both elements are really expensive, so the extension and speed of robotization depends on the capital that a company can invest on the automation transition.

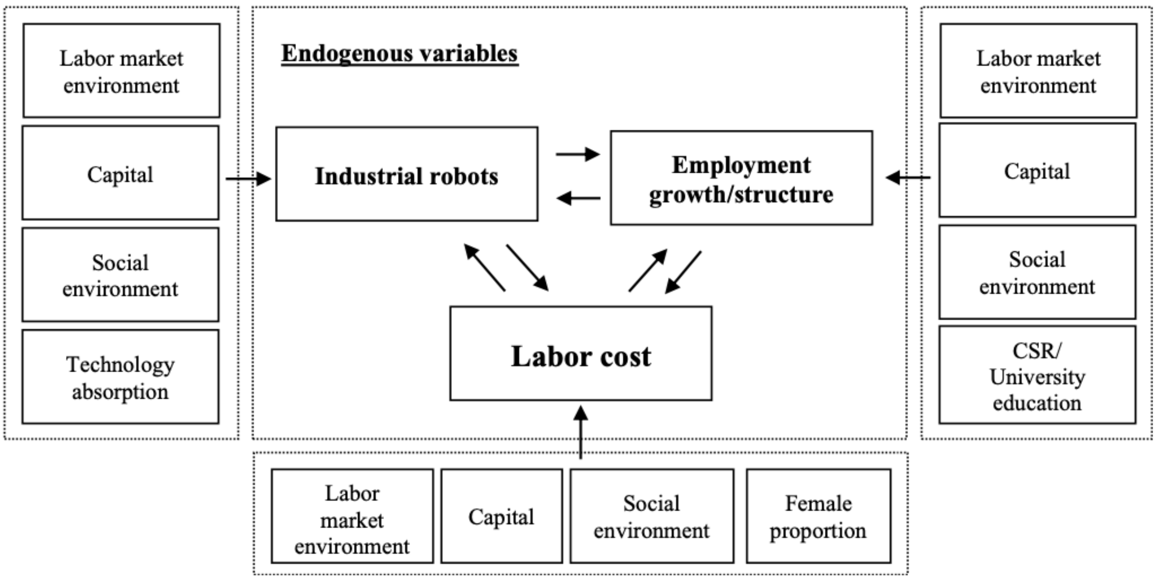
Another factor is the dynamic of the labour market. The choice of the activities to automate cannot ignore the quality, supply, demand and cost of human work related to each specific activity.

The fourth influencing element relates to the economic benefits. These not only focus on reducing labour cost, but can include improvements in production, safety, quality and a noticeable decrease of human mistakes. Analysing the transition with the company point of view, evident positive effects can even outweigh the issue of replacing human labour.

The last factor proposed by the McKinsey report is the regulatory and social acceptance. The adoption of a technology can be influenced by regulation, especially for multinational or big firms, but also by the reaction of users or stakeholders and by government policy.

In addition to these influencing aspects, Jung and Lim evaluated different variables to exam the nexus between industrial robots and labour in terms of quality and quantity of employment, at a more macro-level, performing an empirical analysis on 42 countries for the period 2001-2017. In the Figure 9 is represented the analytical framework of the simultaneous equation system with the two-way causal relationships among the three endogenous variables – adoption of industrial labour, employment growth rate and labour cost. Each of these is influenced by exogenous variables which add other factors to the analysis.

Figure 9. Analytical framework of the simultaneous equation system



Source: JUNG, J.H., LIM, D.G., 2020. *Industrial robots, employment growth, and labour cost: A simultaneous equation analysis,* Technological Forecasting & Social Change, Elsevier. DOI: https://doi.org/10.1016/j.techfore.2020.120202.

Labour market environment affects firms' employment strategies and, consequently, labour demand. The introduction of robots in companies depends, directly, from the labour market condition and the labour cost of the human work. If the labour cost increases companies will evaluate to substitute it with robots, instead if the cost of robotization is higher is more probable that firms will prefer to employ workers.

The cost of purchasing and installing robotics for spot welding in the USA automotive industry, as described by Acemoglu and Autor (2011) in another paper, has declined from $ 182,000 in 2005 to $ 133,000 in 2014 and expected to arrive to $103,000 by 2025. Also, the cost of electronics and electrical has decreased and a generic robotics system has declined through the years and in 2020 arrived to cost $ 20 per hour, which is under the cost of human labour in the United States where the analysis has been made. Not every country has advantages in introducing robotization: Australia where the cost of human labour is $ 55 per hour has more benefits, India where the cost of human labour is $ 5.24 has less advantages.

Moreover, the capital is another factor included by Jung and Lim, both in the point of view of the physical capital and human capital. The former is important because company have to be able financially to speed the introduction of robots or to invest in automation transition. The latter is relevant in order to contribute to the firm's growth and, subsequently, employment growth. As reported by Autor et al. (2011), investing in human capital, implementing the creative intelligence and the social intelligence, could be the winning move to face up the technological transition, always faster in the future.

The country-specific social environment, in addition, influenced the expansion of robots and its relation to labour demand. For instance, in a social environment where efficiency is important, there will be less disagreement about the robots' substitution and subsequent labour replacement; instead, in an environment where social priority is part of the worker welfare, there will be lee likelihood of extensive robotization threatening job stability.

At a micro-level of analysis, there are relevant factors that characterize and influence the positive or negative correlation between automation and employment. Souto-Otero et al. (2021), in their paper, analysed which variables are more impactable at a firm-level. They evaluated six different hypotheses using the dataset "Business Performance and Skills Survey" in Singapore. This city-state has a highly developed and competitive market economy, with one of the highest GDP per capita, low levels of unemployment and most flexible labour markets in the world. In addition, the quality of education is high like, also, the advanced technological infrastructure.

In this scenario there is little evidence that higher levels of skills within the company are negatively associated with labour substitution.

The workforce development initiatives, such as career planning and training, and higher levels of job autonomy are not factors that block the expansion of robots or disincentivize the labour substitution.

Factors like high value-added business strategy and management's perception of effort are negatively associated with labour substitution.

The final evidence regards the lack of management perceptions on workforce competence, which is positively associated with labour substitution, meaning that if the management doesn't recognize the capacity and competences of the workers will be more probable the robot's replacement.

However, it's important to highlight that several aspects that influence the level of employment or unemployment and the evolution of the robotization in the next years are difficult to forecast. Summarizing, relevant factors are the routine-intensity of labour, the cognitive or manual job, the worker skills, the robot productivity, the employment demand, the country's characteristics, the susceptibility of occupation to robotization, the relative prices of capital and labour and the capacity of companies to capitalize automation impact in different ways. For example, related to the last aspect cited, the German Minister of Economic Affairs described that in 2019, in Germany, just the 18% of all the companies in the country knew the concept of "Industry 4.0" and just the 4% have started some internal projects of digitalization.

2.3 – TRENDS AND FUTURE EXPECTATIONS

As demonstrated previously the occupation that can be fully automated, nowadays, are less than 5 percent but, however, the 60 percent of jobs are composed by activities that are for one-third automatable.

In addition, depending on the speed of adoption, from 0 to 30 percent of hours worked globally could be automated by 2030, with a range from 10 million, in the introduction of robotization is slow, to 800 millions of jobs displaced, if the insertion is fast.

Moreover, always depending on the speed of adoption of automation, the workforce that could need to change occupational category ranges from 0%, if slow, to 14% if the transition process is fast.

The jobs losses, in the future, can be replaced by new occupations in new sectors or in emerging industries after the introduction of robots in companies. Following this point of view, the McKinsey Global Institute wrote down a report in 2017 analysing the possible future scenario of employment based on the current spending and investment observed across countries.

The main labour demand trends in the near future are:

- Rising incomes and consumption, especially in emerging countries: global consumption is expected to grow by 23$ trillion until 2030 with higher percentage deriving especially from emerging countries with impacts not only on the country itself but, also, on countries that export to the most consumerist countries. This situation is expected to produce 250-280 millions of new jobs due to the evolution of economies.

- Increase of the age of population: estimation of population increase is around of 300 million more people aged 65 or older by 2030, generating demand for more jobs related to healthcare and similar sectors. The growth is expected to be from 50 million to 85 million by 2030.

- Development and deployment of technology: technological devices will always grow in the future and jobs related to informatics, telecommunications, electronics and digital are estimated to increase as well. The approximation for working is the creation of 20-50 million new occupations globally.

- Investments in infrastructure and buildings: to improve the technological environment, especially the emerging countries need to bridge the infrastructure gap and get the better of the housing shortage. The creation of new jobs will be up to 80 million, and if the issue would receive more investments the new occupations could rise to 200 million.

- Investments in renewable energy and climate adaptation: the energetic transition is another growing trend of the last years, determined by the importance of improving the energetic efficiency and consumption. The investments in this field are huge and the expected creation of new jobs is up to 10 millions of occupation in the sector of renewable energy.

- "Marketization" of previously unpaid domestic work: jobs related to the care service, cleaning, cooking or gardening can become an effective occupation for thousands of people. The estimation is around 50 to 90 millions of new jobs globally.

In this scenario lots of changes are expected, but the common deduction is that there will be a shift of the competences required by the market and, by the report, from 75 to 375 million people should learn new skills and will be displaced from the current position. Automation, as well, is one of the reasons of the shift and in the world the impact could displace from 400 to 800 million people. In China is expected a shift effect of the 12% by 2030 due to automation introduction; in United States, at the other side, of one-third of the labour force.

The past technological revolutions, however, caused displacement effects and unemployment in the short term, but those lost jobs were offset by new occupations. The same scenario is expected for the revolution in progress and, as analysis reported for the six countries took into consideration which are China, Germany, India, Japan, Mexico and United States, if displaced workers will be reemployed in one year, the economy will be boost under different points of view: productivity increases, wages grow, and people work.

In general, the workers of the future are more involved in activities that machines are not able to do, and for this reason, skills and competences require a shift too, in fact those activities typically required higher educational level such as college degree or advanced degree. The report foresees that, in United States and advanced economies, low-wage occupations and high-wage occupations will increase, instead, middle-wage jobs will decrease largely. Just in emerging economies, such as China and India, the middle-wages occupations will increase.

CHAPTER 3 – DATASET AND DATA EXPLORATION

The study is based on a panel of 30 countries, both advanced and developing ones, for the years from 2011 to 2018, selected from the International Federation of Robotics (IFR) database in relation to the robotics data used for the cross-country analysis.

The analysed 30 countries are:

- Austria
- Belgium
- Brazil
- Canada
- China
- Czech Republic
- Denmark
- Finland
- France
- Germany
- Hungary
- Indonesia
- Italy
- Mexico
- Netherland
- Norway
- Poland
- Portugal
- Romania
- Russian Federation
- Singapore
- Slovakia
- Spain
- Sweden
- Switzerland
- Thailand
- Turkey
- United Kingdom
- United States
- Vietnam

Brazil, China, Indonesia, Romania, Russian Federation, Singapore, Thailand and Vietnam (8) are developing countries, instead the others are developed countries (22) following the OECD classification.

For each analysed country in the period 2011-2018, the IFR Statistical Department evaluated the number of industrial robots deployed. The definition of industrial robot applied by IFR is "An automatically controlled, reprogrammable, multipurpose manipulators programmable in three or more axes, which may be either fixed in place or mobile for use in industrial automation applications"[6]. The IFR World Robotics of 2020 reported the classification of 39 applications of industrial robotics, represented in Table 2, describing the application area and a brief definition of the robotic operations.

[6] Definition of industrial robot is given by the International Organization for Standardization (ISO 8373).

Table 2. Desk classification for grouping application.

IFR Class	Group	Application Area	Definitions
110	**1**	**Handling operations / Machine Tending**	**Assistant processes for the primary operation**
111	1	Metal casting	Including die-casting
112	1	Plastic moulding	Also inserting operations for injection moulding
113	1	Stamping forging, bending	
114	1	Handling operations at machine tools	
115	1	Machine tending for other processes	e.g. handling during assembly, handling operations during glass or ceramics production or food production
116	1	Measurement, inspection, testing	Triage, quality inspection, calibrating
117	1	Palletizing	All sectors, all kinds and sizes of pallets
118	1	Packaging, picking, placing	e.g. operations during primary and secondary packaging
119	1	Material handling	e.g. transposing, handling during sandcasting
120	1	Handling operations unspecified	
160	**2**	**Welding and soldering**	
161	2	Arc welding	
162	2	Spot welding	
163	2	Laser welding	
164	2	Other welding	e.g. ultrasonic welding, gas welding, plasma welding
165	2	Soldering	
166	2	Welding unspecified	
170	**3**	**Dispensing**	
171	3	Painting and enamelling	Area-measured application of lacquer (surface coat)
172	3	Application of adhesive, sealing material	Spot-wise and line-wise
179	3	Others dispensing/spraying	e.g. powder coating, application of mould release agent, area-measured application of adhesive, spraying of wax to conserve
180	3	Dispensing unspecified	
190	**4**	**Processing**	**Enduring changing, the robot leads the workpiece or the tool, material removal**
191	4	Laser cutting	

192	4	Water jet cutting	
193	4	Mechanical cutting/grinding/deburring....	
198	4	Other processing	e.g. gas/plasma cutting, drilling, bending, punching, shearing
199	4	Processing unspecified	
200	**5**	**Assembling and disassembling**	**Enduring positioning of elements**
201	5	Assembling	Assembling, mounting, screw/nut-driving, clinching, reveting, bonding
203	5	Disassembling	Recycling, removal of cover after processing
209	5	Assembling unspecified	
900	**6**	**Others**	
901	6	Cleanroom for FPD	
902	6	Cleanroom for semiconductors	
903	6	Cleanroom for others	
905	6	Others	
999	**7**	**Unspecified**	

Source: MULLER, C., KUTZBACH, N., 2020. World Robotics 2020 – Industrial Robots, IFR Statistical Department, VDMA Services GmbH, Germany.

Following IFR (2020), for the cross-country analysis each application has been assigned to a group, through a desk classification, so to create six clusters based on the characteristics of the robotics applications. These clusters, reported more in detail in Table 2, are the following:

Group 1 – Handling operations / Machine Tending

Group 2 – Welding and soldering

Group 3 – Dispensing

Group 4 – Processing

Group 5 – Assembling and disassembling

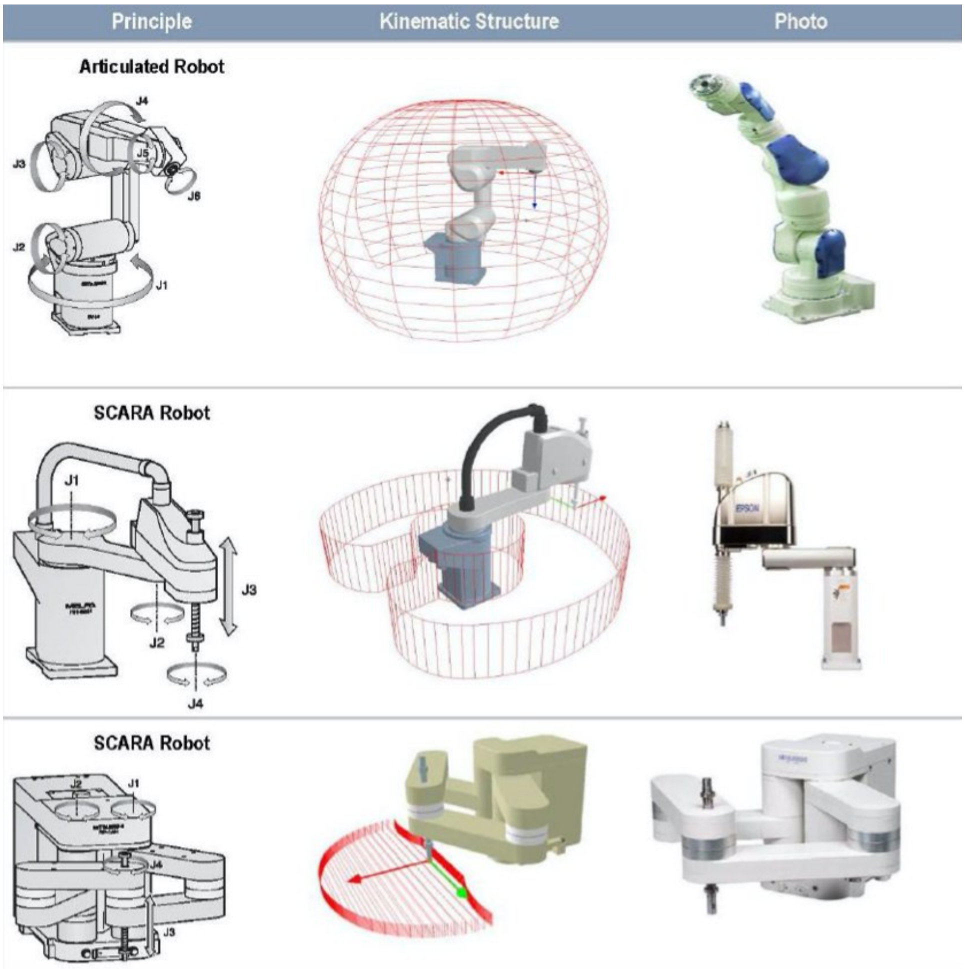
Group 6 – Others

Group 7 – Unspecified (this class is not used in the analysis because it’s not related to a type of industrial robots)

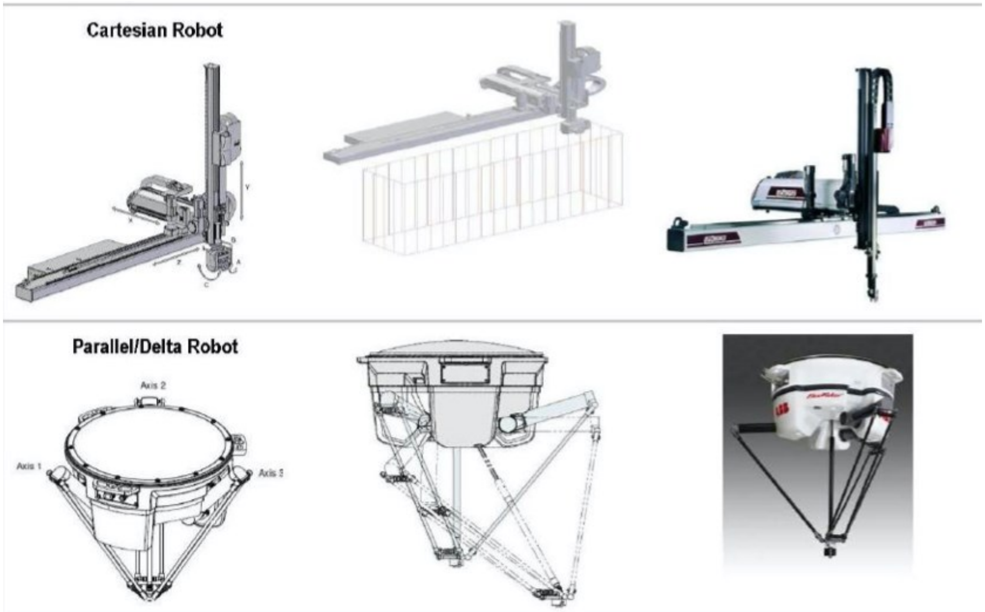
Each application is performed by different type of industrial robots, classified by the mechanical structure. The classification reported six categories and represented in Figure 10:

- Articulated robot: a robot whose arm has at least three rotary joints
- Cartesian (linear/gantry) robot: robot whose arm has three prismatic joints and whose axes are correlated with a cartesian coordinate system
- Cylindrical robot: a robot whose axes form a cylindrical coordinate system
- Parallel/Delta robot: a robot whose arms have concurrent prismatic or rotary joints
- SCARA robot: a robot, which has two parallel rotary joints to provide compliance in a plane
- Others: Robots not covered by one of the above classes[7]

Figure 10. Classification of industrial robots by mechanical structure.



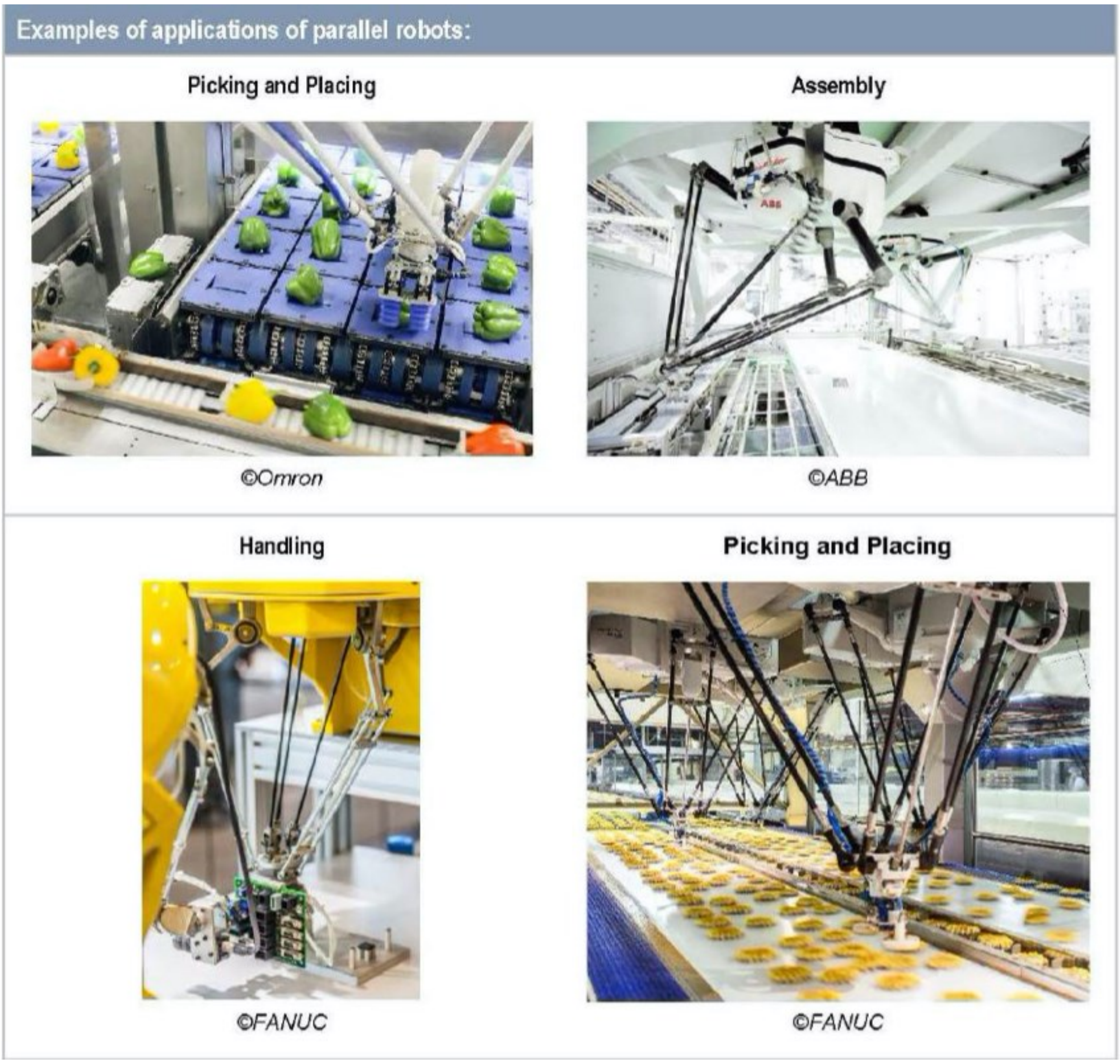
[7] Source: MULLER, C., KUTZBACH, N., 2020. World Robotics 2020 – Industrial Robots, IFR Statistical Department, VDMA Services GmbH, Germany.



Source: MULLER, C., KUTZBACH, N., 2020. World Robotics 2020 – Industrial Robots, IFR Statistical Department, VDMA Services GmbH, Germany.

An example of the parallel/Delta robot used in different applications, in this case handling, picking and placing and assembly. (Figure 11)

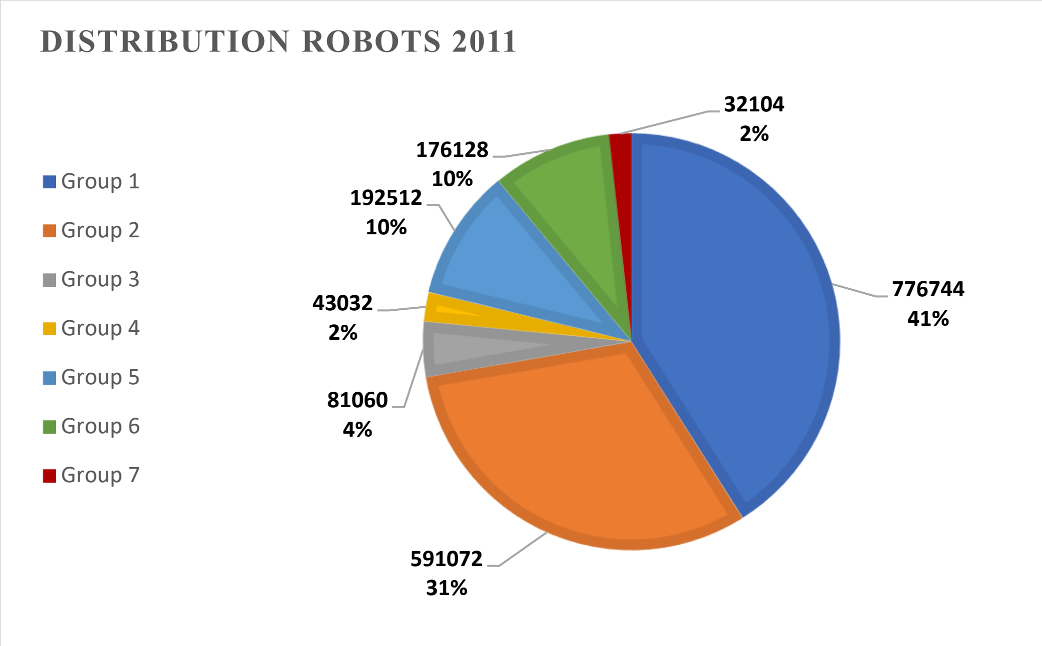
Figure 11. Parallel/Delta robot examples.

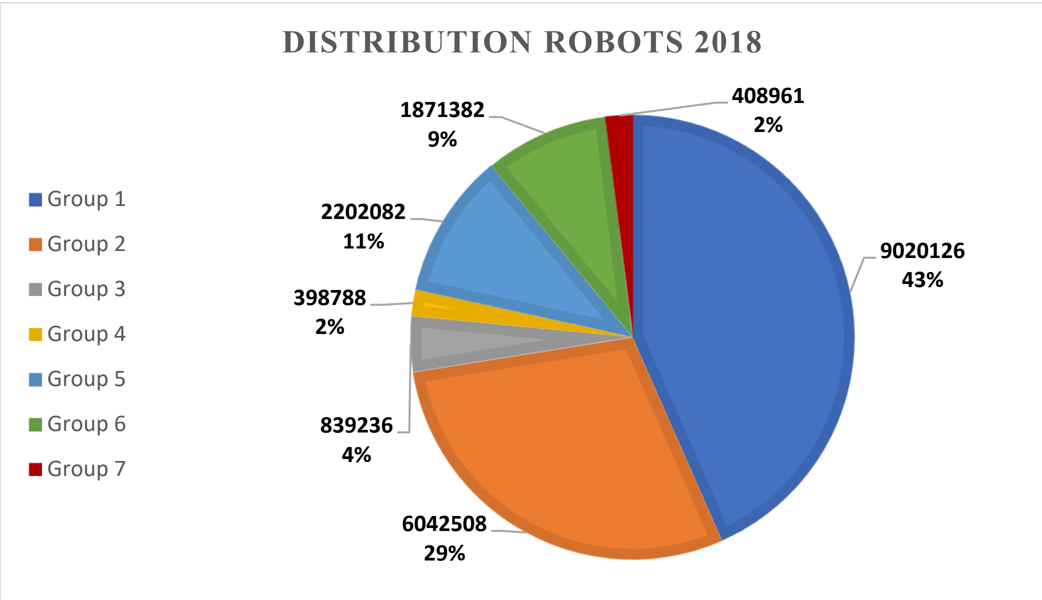


Source: MULLER, C., KUTZBACH, N., 2020. World Robotics 2020 – Industrial Robots, IFR Statistical Department, VDMA Services GmbH, Germany.

Every industrial robot's application is related to a value of "Operational Stock" within each country for every year analysed. This variable represents the number of robots currently deployed, calculated by the IFR Statistical Department, that assumed an average life of the robots of 12 years with an immediate withdrawal from service afterwards.

Figure 12. Industrial robot distribution in 2011 and in 2018.





Source: Own Dataset.

In Figure 12, the representation of the industrial robots deployed in 2011 and in 2018 divided in the groups of application. Between these two years, which are the period of the cross-country analysis following explained, the number of industrial robots has grown for 11 times, which correspond to the 995%. The distribution of every individual group of application doesn't change so much, demonstrating a homogeneous growth of robotization globally.

By merging the IFR robot data with variables from International Labour Organization (ILO) and the World Bank Database, the final dataset derives from the aggregation of industrial robots' applications and operational stock data with variables related to educational level, distinguished between basic, intermediate and advanced education, average wage in every country, population, labour force level and robot density, which is the ratio between operation stock and population.

From the ILO Database, we retrieve the variables "Education TOT", "Basic education", "Intermediate education", "Advanced education" and "Average Wage". In particular, the ones related to educational level from the dataset "Employment by sex, age and education (thousands) – Annual", and the last one about the wages, instead, from the dataset "Mean nominal monthly earnings of employees by sex and economic activity – Annual".

The description of the "Employment by sex, age and education (thousands) – Annual" dataset is "the employed comprise all persons of working age who, during a specified brief period, were in one of the following categories: a) paid employment (whether at work or with a job but not at work); or b) self-employment (whether at work or with an enterprise but not at work). Data are disaggregated by level of education, which refers to the highest level of education completed, classified according to the International Standard Classification of Education (ISCED)."[8] In some countries there are additional specification for the educational level, which are "Less than basic" or "Unstated level", but for the low relevance of those data they are not considered. Moreover, distinction between male and female has not been considered, but was used the total amount, which is the sum of them.

Table 3. ISCED Classification of educational levels.

Basic Education	Primary School and Secondary School
Intermediate Education	High School
Advanced Education	Bachelor's degree and Master's degree

Source: http://uis.unesco.org/sites/default/files/documents/international-standard-classification-of-education-isced-2011-en.pdf

The description of the "Mean nominal monthly earnings of employees by sex and economic activity – Annual" dataset is "the earnings of employees relate to the gross remuneration in cash and in kind paid to employees, as a rule at regular intervals, for time worked or work done together with remuneration for time not worked, such as annual vacation, other type of paid

[8] https://www.ilo.org/shinyapps/bulkexplorer36/?lang=en&segment=indicator&id=EMP_TEMP_SEX_AGE_EDU_NB_A

leave or holidays. This is a harmonized series: data reported as weekly and yearly are converted to monthly in the local currency series, using data on average weekly hours if available; and data are converted to U.S. dollars as the common currency, using exchange rates or using 2017 purchasing power parity (PPP) rates for private consumption expenditures. The latter series allows for international comparisons by taking account of the differences in relative prices between countries."[9] The "Average Wage" considered not just the wage level, but also other components than impacted it, like taxes or inflated social security contributions. This variable has been considered for the manufacturing sector because is the most impacted by robotization for the total employees, without distinction between male and female, but was used the total amount, which is the sum of them.

From the World Bank Database, the variables aggregated to the dataset are "Population", "Labour Force". Population derives from the counts of all residents regardless of legal status or citizenship in each country for every year. Labour force comprises people ages 15 and older who supply labour for production of goods and services during a specified period. It includes people who are currently employed and people who are unemployed but seeking work as well as first-time jobseekers. Not everyone who works is included, however. Unpaid workers, family workers, and students often are omitted and in some countries are not counted members of the armed forces. Labour force size tends to vary during the years because of the seasonal workers. Both variables have been considered for each different year.

The cross-country analysis was conducted using the relative ratios between some variables, in particular:

- Basic Education / Population
- Intermediate Education / Population
- Advanced Education / Population
- Advanced Education / Basic Education
- Robot Density

Robots Density is the ratio between Operational Stock and Labour Force and determines the level of industrial robots related to the labour force level. IFR report (2020) described the Robot Density as "the number of multipurpose industrial robots in operation per 10,000 persons employed"[10]. This variable is used because the absolute number of units of industrial robots

[9] https://www.ilo.org/shinyapps/bulkexplorer25/?lang=en&segment=indicator&id=EAR_4MTH_SEX_ECO_CUR_NB_A
[10] Source: MULLER, C., KUTZBACH, N., 2020. World Robotics 2020 – Industrial Robots, IFR Statistical Department, VDMA Services GmbH, Germany.

could be misleading when comparing countries of different economic sizes. Robot density captures cross-sectional variations of countries and longitudinal variations over time allowing more accurate comparisons.

The dataset resulted from the implementation of all the variable previously described it’s been used to conduct the cross-country analysis and understand the correlation relations between them and the employment dynamics.

CHAPTER 4 – CROSS-COUNTRY ANALYSIS

The cross-country analysis has the purpose to highlight whether, and to what extent, a higher robot density impacts the employment level and quality in a country. In particular, we test whether the introduction of robots impacts the labour force, the worker skills determined by the educational level, divided in the three level, basic, intermediate and advanced, and wages.

The econometric analysis develops along the following steps. First, we use a series of three-way fixed effects regressions, where country-specific, year-specific, and application-specific unobserved components are controlled for. Second, we split the sample across groups of robot applications, and we re-estimate our econometric model using two-way fixed effects regressions, where we control for country- and time-specific effects. In this way, we test whether the results emerging from the three-way fixed effects hold, or differ, across the type of robot applications. Third, we also provide a further set of robustness tests, where we check whether our results vary in different country settings, namely those made by OECD countries and developing countries. Finally, we try to test for the direction of causality between robot density and employment using a dynamics specification and a Generalized Method of Moments (GMM) approach.

The baseline econometric model is the following:

$$lnY_{ita} = \beta_1 lnRD_{ita} + \mu_i + \theta_t + \delta_a + \varepsilon_{ita} \tag{1}$$

where

Y is the dependent variable, in terms of level and quality of employment, LF, BASICPOP, MEDIUMPOP, ADVPOP, ADVBASIC, WAGE

β_1 : partial elasticity of the employment with respect to robot density

$lnRD_{ita}$: Robot Density variable transformed in natural logarithm (while replacing the 0 values with a 0.1 value)

μ_i: vector of country-specific dummies, that captures country fixed effects, or time-invariant unobserved characteristics (e.g. quality of institutions, quality of infrastructures…) which can be potentially correlated with RD

θ_t: vector of year-specific dummies, included to control, for example, for the role of the business cycle or of macroeconomics shocks (like the 2008 financial crisis)

δ_a: vector of application-specific dummies. It captures the robot application fixed effects, intrinsic characteristics of robots, captured through like the type of task performed

ε_{ita}: stochastic error component

We have also clustered the standard errors at the country level to reduce the risk of unobserved arbitrary correlation that might arise within groups of observations.

The first analysis is represented in Table 4, which reports the result of the OLS regression, using the three-way fixed effects previously described, and wants to explain how the robot density is correlated with labour force, the worker skills, captured by the three levels of educational level, basic, intermediate and advanced, and the average wage level.

Table 4. Pooled OLS three-way fixed effects regressions.

	(1)	(2)	(3)	(4)	(5)	(6)
DEP. VAR.	ln_lf	ln_basicpop	ln_mediumpop	ln_advpop	ln_advbasic	ln_wage
ln_robot	-0.000	0.000	-0.000	-0.000	-0.000	-0.000
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
Country FE	✓	✓	✓	✓	✓	✓
Year FE	✓	✓	✓	✓	✓	✓
App FE	✓	✓	✓	✓	✓	✓
N	9360	9360	9360	9360	9360	9360
R^2	0.999	0.997	0.993	0.910	0.919	0.940

Country-clustered standard errors in parentheses. * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$

Source: own analysis.

The results in Column 1- 6 reveal that there is not a statistically significant relationship between ln*RD* and our employment related variables. In each column, once controlled for country, year, and application fixed effects (FE), the estimated β_1 remains statistically equal to zero. We also note that the R^2 is always above 0.9, meaning that the model explains almost all the heterogeneity in employment dynamics across countries and years.

In addition, we have also computed the Variance Inflation Factors (VIF) statistic, which allows testing whether there is multicollinearity among the variables. In our case, the maximum VIF statistic is 1.94, which is less than the commonly accepted threshold of 5, meaning that multicollinearity does not represent an issue.

The results show that robots do not determine a higher educational level, or higher wages, for a country's workforce. The effects, however, can be actually equal to 0 or it can be that some compensation mechanisms are at work that balance positive and negative effects. For example, a higher exposure to robots can correspond to a reduction in the manufacturing employment, in front of a higher employment in the service sector, making the final result equal to 0. Or it can be that a fall in employment in one region is counter-balanced by an increase in employment in other regions of the same country.

In order to test the robustness of these results, we have conducted three additional tests, two of which are reported in the Appendix. Since some observations, related to the operational stocks of industrial robots in some countries and years were equal to 0, we have replicated the regression using three different versions of our main variable, robot density. In the first, we have dropped all the observations with 0 values in the operational stocks of robots, reducing the number of observations to 7542. In the second, we have operated the following logarithmic transformation ln*RD* = ln(robot_density+1) adding 1 to the value of robot density. The estimates are presented in the Appendix, Tables A1 and A2. We do not find any change in the results.

An additional test is presented in Table 5, where we use the absolute values of our variables without any logarithmic transformation.

Table 5. Pooled OLS three-way fixed effects: absolute values.

	(1)	(2)	(3)	(4)	(5)	(6)
DEP. VAR.	LF	BASIC/POP	MED/POP	ADV/POP	ADV/BAS	WAGE
Robot	-1.420e+08	0.001	-0.001	0.000	2.727	2317.6
	(8.463e+07)	(0.000)	(0.001)	(0.000)	(18.144)	(18186.7)
Country FE	✓	✓	✓	✓	✓	✓
Year FE	✓	✓	✓	✓	✓	✓
App FE	✓	✓	✓	✓	✓	✓
N	9360	9360	9360	9360	9360	9360
R^2	0.999	0.993	0.981	0.986	0.990	0.968

Country-clustered standard errors in parentheses. * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$

Source: own analysis.

Again, any of the results is statistically significant, demonstrating that there is not any difference from the results shown in Table 4.

To better analyse the impact of robotization on employment dynamics and try to find some significant results, we have split the sample according to: (i) the cluster of robot applications; (ii) the type of country, according to its level of wellbeing.

As regard point (i), we have created six different panels, using the six application clusters defined in Chapter 3: Handling operations/Machine Tending, Welding and soldering, Dispensing, Processing, Assembling and disassembling, Others. Each panel consists of 30 countries observed across 8 years, for a total number of observations of 240.

Then, we proceed estimating the following equation:

$$lnY_{it} = \beta_1 lnRD_{it}^{a} + \mu_i + \theta_t + u_{it} \qquad (2)$$

for each of the six groups of applications a (where $a = 1, \ldots 6$) separately. To control for possible time-invariant unobserved country characteristics that might correlated with lnRD, we estimate Equation 2 using a panel fixed effect (FE) estimator, in which all the variables are subject to a *within* transformation, i.e. by subtracting the sample mean from each of them in order to delete μ_i. The results are presented in Tables 6-11.

Table 6. Group 1: Handling operations/Machine tending.

	(1)	(2)	(3)	(4)	(5)	(6)
DEP. VAR.	ln_lf	ln_basicpop	ln_mediumpop	ln_advpop	ln_advbasic	ln_wage
ln_robot	0.004	0.065**	0.032	-0.023	-0.088	0.186***
	(0.011)	(0.027)	(0.026)	(0.067)	(0.075)	(0.061)
Year FE	✓	✓	✓	✓	✓	✓
Country FE	✓	✓	✓	✓	✓	✓
N	240	240	240	240	240	240
R^2 tot	0.027	0.000	0.088	0.001	0.008	0.593
R^2 within	0.439	0.403	0.064	0.117	0.178	0.200
R^2 between	0.308	0.002	0.102	0.128	0.139	0.643

Country-clustered standard errors in parentheses. * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$
Source: own analysis.

We find a statistically significant (at the 5% level) correlation between robot density and "basicpop", which is the part of population with a basic education, and a high (at the 1% level) statistically significant correlation between robot density and average wages.

Specifically, we find that a 10% increase in robot density corresponds to an average 0.7% increase in the share of low-educated population and a 2% increase in the level of monthly wages in a country.

Table 7. Group 2: Welding and soldering

	(1)	(2)	(3)	(4)	(5)	(6)
DEP. VAR.	ln_lf	ln_basicpop	ln_mediumpop	ln_advpop	ln_advbasic	ln_wage
ln_robot	0.014*	0.050	0.020	-0.012	-0.063	0.152**
	(0.007)	(0.033)	(0.025)	(0.044)	(0.052)	(0.063)
Year FE	✓	✓	✓	✓	✓	✓
Country FE	✓	✓	✓	✓	✓	✓
N	240	240	240	240	240	240
R^2 tot	0.042	0.020	0.024	0.007	0.002	0.296
R^2 within	0.460	0.387	0.058	0.117	0.176	0.181
R^2 between	0.086	0.044	0.033	0.046	0.155	0.315

Country-clustered standard errors in parentheses. * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$
Source: own analysis.

As reported in Table 7, we find a statistically significant (at the 10% level) correlation between robot density and "labour force", which includes the part of population with 15 or over years old that are currently employed and people who are unemployed but seeking work as well as first-time jobseekers. Moreover, we find a statistically significant (at the 5% level) correlation between robot density and average wages.

In particular, a 10% increase in robot density corresponds to an average 0.15% increase in the labour force level and a 1.5% increase in the level of monthly wages in a country.

Table 8. Group 3: Dispensing

	(1)	(2)	(3)	(4)	(5)	(6)
DEP. VAR.	ln_lf	ln_basicpop	ln_mediumpop	ln_advpop	ln_advbasic	ln_wage
ln_robot	0.009	0.030	0.002	-0.026	-0.056	0.109
	(0.008)	(0.028)	(0.023)	(0.067)	(0.075)	(0.068)
Year FE	✓	✓	✓	✓	✓	✓
Country FE	✓	✓	✓	✓	✓	✓
N	240	240	240	240	240	240

R^2 tot	0.027	0.008	0.002	0.004	0.000	0.342
R^2 within	0.447	0.368	0.054	0.118	0.176	0.158
R^2 between	0.115	0.050	0.051	0.051	0.174	0.421

Country-clustered standard errors in parentheses. * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$
Source: own analysis.

We don't find any statistically significant correlation between robot density and the considered variables for the dispending robot's application.

Table 9. Group 4: Processing

	(1)	(2)	(3)	(4)	(5)	(6)
DEP. VAR.	ln_lf	ln_basicpop	ln_mediumpop	ln_advpop	ln_advbasic	ln_wage
ln_robot	0.002	0.039	0.012	-0.033	-0.071	0.079
	(0.006)	(0.025)	(0.018)	(0.056)	(0.064)	(0.073)
Year FE	✓	✓	✓	✓	✓	✓
Country FE	✓	✓	✓	✓	✓	✓
N	240	240	240	240	240	240
R^2 tot	0.005	0.012	0.056	0.002	0.029	0.598
R^2 within	0.438	0.392	0.057	0.118	0.179	0.159
R^2 between	0.267	0.030	0.099	0.144	0.258	0.739

Country-clustered standard errors in parentheses. * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$
Source: own analysis.

Again, we don't find any statistically significant correlation between robot density and the considered variables, meaning that the industrial robots related to processing applications don't impact the other variables analysed.

Table 10. Group 5: Assembling and disassembling

	(1)	(2)	(3)	(4)	(5)	(6)
DEP. VAR.	ln_lf	ln_basicpop	ln_mediumpop	ln_advpop	ln_advbasic	ln_wage
ln_robot	0.008	0.029	0.025**	0.025	-0.003	0.048
	(0.006)	(0.019)	(0.012)	(0.020)	(0.026)	(0.038)
Year FE	✓	✓	✓	✓	✓	✓
Country FE	✓	✓	✓	✓	✓	✓
N	240	240	240	240	240	240
R^2 tot	0.082	0.027	0.020	0.033	0.013	0.427
R^2 within	0.455	0.384	0.072	0.118	0.175	0.148
R^2 between	0.200	0.065	0.021	0.051	0.199	0.596

Country-clustered standard errors in parentheses. * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$
Source: own analysis.

We don't find any statistically significant correlation between robot density and the considered variables for the assembling and disassembling robot's application.

Table 11. Group 6: Other

	(1)	(2)	(3)	(4)	(5)	(6)
DEP. VAR.	ln_lf	ln_basicpop	ln_mediumpop	ln_advpop	ln_advbasic	ln_wage
ln_robot	-0.004	0.009	0.033**	0.043	0.034	0.082**
	(0.005)	(0.009)	(0.015)	(0.030)	(0.033)	(0.037)
Year FE	✓	✓	✓	✓	✓	✓
Country FE	✓	✓	✓	✓	✓	✓
N	240	240	240	240	240	240
R^2 tot	0.033	0.001	0.026	0.061	0.074	0.585
R^2 within	0.444	0.362	0.093	0.121	0.176	0.182
R^2 between	0.195	0.036	0.027	0.095	0.211	0.705

Country-clustered standard errors in parentheses. * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$
Source: own analysis.

As reported in Table 11, we find a statistically significant (at the 5% level) correlation between robot density and "mediumpop", which is the part of population with a intermediate education, and, a statistically significant (at the 5% level) correlation between robot density and average wages.

In particular, a 10% increase in robot density corresponds to an average 0.3% increase in the share of medium-educated population and a 0.8% increase in the level of monthly wages in a country.

The Fixed Effects estimator, tested individually for the six different groups of application, demonstrates that the high significant positive correlation between robot density and average wages are explained from three groups of robot's application, in particular from Group 1 (Handling operations/Machine tending), Group 2 (Welding and soldering) and Group 6 (Other).

These three groups of specific robotics applications explain that the increase of 10% in robot density is correlated with an increase of the 2% of the average wages in the 30 countries for the eight years considered. The reason of this result, that only these three applications have an impact, could be that these three robotics applications require more specialized and qualified technicians.

4.2 – Dynamic Specification

In order to understand the causal relationship between robot density and wages, we use the Blundell–Bond (1998) estimator, which uses the generalized method of moments (GMM) estimator to estimate dynamic panel models. The dynamic models are used because they are able to show the causality direction between two variables even if the phenomenon is already in progress or it is based on several macroeconomics data, like in this case, thanks to the use of internal panel data already collected, that can be used as instruments for the potentially endogenous variables. In our case, we can suppose that a higher wage rate, which means a higher labour cost, can induce firms – and countries – to install industrial robots in order to save on future production costs. If this is true, the direction of causality would run from wages to industrial robots, and not vice-versa.

The Blundell and Bond (1998) estimation begins by first differencing all variables in order to remove the unobserved fixed effects, and then using the GMM. Such an approach is also defined as "system GMM" because the equation in first difference is augmented by making the additional hypothesis that the first differences of instrumental variables are not correlated with the fixed effects. In this way, a system of two equations – one in levels and one in first differences – is generated and estimated simultaneously.

The linear equation is the following:

$$lnW = \gamma_1 lnW_{it-1} + \gamma_2 lnRD_{it} + \mu_i + \theta_t + u_{it} \tag{3}$$

where

W: dependent variable, wage

W_{it-1}: one-year lag of the dependent variable

RD_{it}: time-variant

μ_i: time-invariant country-specific dummies

θ_t: time-invariant year-specific dummies

u_{it}: stochastic error component

In this dynamic model, for construction, W_{it-1} and RD_{it} are correlated with the error term u_{it}. In order to make them exogeneous, we need a set of instruments which can explain the dynamics of the endogenous variables, i.e. wages at t-1 W_{it-1} and the robot density RD_{it}, but are not correlated with the dependent variable.

In this equation, variables in levels are instrumented with all the lags of their own first differences. The assumption needed is that these differences are uncorrelated with the unobserved country effects.

The equation in first differences, instead, is the following:

$$\Delta lnW = \gamma_1 \Delta lnW_{it-1} + \gamma_2 \Delta lnRD_{it} + \theta_t + u_{it} \tag{4}$$

This latter is used to estimate the "difference GMM" model, in which, as instruments for the first-differenced endogenous variables we use all the corresponding lagged variables in levels. To reduce the number of instruments, we have collapsed them by creating one instrument for each variable and lag distance, rather than one for each time period, variable, and lag distance.

Table 12 shows the results of the system GMM and difference GMM regressions.

Table 12. Dynamic specification: twostep SYS-GMM and DIFF-GMM

	All Group		Group 1		Group 2		Group 6	
DEP. VAR.:	SYS-GMM	DIFF-GMM	SYS-GMM	DIFF-GMM	SYS-GMM	DIFF-GMM	SYS-GMM	DIFF-GMM
ln_wage								
ln_wage_{t-1}	0.943***	0.687***	0.891***	0.341	0.990***	1.149***	0.984***	0.101
	(0.094)	(0.210)	(0.135)	(0.414)	(0.060)	(0.221)	(0.024)	(0.512)
ln*RD*	0.011	0.091	0.041	0.197	-0.040	-0.123	-0.012	0.147
	(0.061)	(0.076)	(0.070)	(0.126)	(0.060)	(0.108)	(0.021)	(0.124)
Year FE	✓	✓	✓	✓	✓	✓	✓	✓
N	210	180	210	180	210	180	210	180
N. instr	16	13	16	13	16	13	16	13
AR(1) *p*	0.079	0.119	0.081	0.330	0.074	0.100	0.079	0.553
AR(2) *p*	0.267	0.348	0.281	0.548	0.275	0.278	0.267	0.821
Hansen *p*	0.315	0.158	0.227	0.202	0.493	0.409	0.206	0.200

Country-clustered standard errors in parentheses. * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$
Source: own analysis.

The results of these regressions show that, the coefficient of ln*RD* is no more statistically significant, demonstrating that the previous result on wages in the Group 1, Group 2 and Group 6, is not robust to endogeneity. This means that the causality relationship is not running from robot density to wages but, on the contrary, from higher wages to higher exposure to industrial robots.

The positive relationship, previously resulted, between robot density and wage is not confirmed for the endogeneity test based on a dynamic model. Therefore, one can lean towards the idea that it is a higher level of wages that push companies and sectors to install robots instead of the other way around.

In the end, robot density has no significant impact on employment and wages in the observed countries: still, either there is no relationship or there are compensation mechanisms at the country and / or sector level.

The higher wages, from the company's point of view, mean higher costs of labour, that boosts the companies to invest in robotization and automation.

At the other side, the higher cost of labour can mean that companies are employing more qualified employees, like engineers or specialized informatics designers, that require higher salaries.

Another explanation could be that the increase of wages derives from a higher productivity of the companies, which require a higher amount of employers and this, consequently, determines also the introduction of robots inside factories.

As regard point (ii), the second part of the cross-country analysis tries to find statistically significant correlation between robot density and the other variables, distinguishing developing countries and OECD countries from the initial pool of 30 countries.

The developing countries are 8: Brazil, China, Indonesia, Romania, Russian Federation, Singapore, Thailand and Vietnam.

The developed countries, following the OECD classification, are 22: Austria, Belgium, Canada, Czech Republic, Denmark, Finland, France, Germany, Hungary, Italy, Mexico, Netherland, Norway, Poland, Portugal, Slovakia, Spain, Sweden, Switzerland, Turkey, United Kingdom, United States.

For these analyses, we use the baseline econometric model (1) explained in the initial part of this chapter distinguishing the two different groups of countries: developing ones and OECD. We repeat for these two samples the three-way fixed effects regressions, where country-specific, year-specific, and application-specific unobserved components are controlled for. Secondly, we estimate the same econometric model dividing the two samples through the six robot's applications and using the two-fixed effects regressions, where we control country-specific and year-specific effects. As before, in this way we can test which groups of robot's applications hold the result of the three-way fixed effects.

The first analyses are represented in Table 13 and Table 14, respectively for the OECD countries and the developing countries, using the three-way fixed effects regressions.

Table 13. Pooled OLS three-way fixed effects for OECD countries.

	(1)	(2)	(3)	(4)	(5)	(6)
DEP. VAR.	ln_lf	ln_basicpop	ln_mediumpop	ln_advpop	ln_advbasic	ln_wage
ln_robot	0.000	0.000	0.000*	0.000**	-0.000	-0.000
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
Country FE	✓	✓	✓	✓	✓	✓
Year FE	✓	✓	✓	✓	✓	✓
App FE	✓	✓	✓	✓	✓	✓
N	6864	6864	6864	6864	6864	6864
R^2	0.999	0.992	0.989	0.984	0.992	0.876

Country-clustered standard errors in parentheses. * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$
Source: own analysis.

Table 14. Pooled OLS three-way fixed effects for developing countries.

	(1)	(2)	(3)	(4)	(5)	(6)
DEP. VAR.	ln_lf	ln_basicpop	ln_mediumpop	ln_advpop	ln_advbasic	ln_wage
ln_robot	-0.000***	-0.000	-0.000	-0.001	-0.001	-0.000
	(0.000)	(0.000)	(0.000)	(0.001)	(0.001)	(0.000)
Country FE	✓	✓	✓	✓	✓	✓
Year FE	✓	✓	✓	✓	✓	✓
App FE	✓	✓	✓	✓	✓	✓
N	2496	2496	2496	2496	2496	2496
R^2	0.999	0.999	0.993	0.884	0.848	0.984

Country-clustered standard errors in parentheses. * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$
Source: own analysis.

The results in Columns 1-6 reveal that there is not a statistically significant relationship between ln*RD* and our employment related variables for both OECD and developing countries. In each column, once controlled for country, year, and application fixed effects (FE), the estimated β_1 remains statistically equal to zero. We also note that the R^2 is always above 0.88, meaning that the model explains almost all the heterogeneity in employment dynamics across countries and years.

We proceed estimating the two-way fixed effects regressions using the Equation (2) for each of the six groups of applications separately. In this estimator all the variables are subject to a *within* transformation, i.e. by subtracting the sample mean from each of them in order to delete μ_i. The results are presented in Tables 17-22.

Table 17. Panel FE estimates OECD countries for Group 1 – Handling operations/Machine tending

	(1)	(2)	(3)	(4)	(5)	(6)
DEP. VAR.	ln_lf	ln_basicpop	ln_mediumpop	ln_advpop	ln_advbasic	ln_wage
ln_robot	0.019	0.088*	0.065**	0.017	-0.070	0.144
	(0.013)	(0.044)	(0.030)	(0.036)	(0.046)	(0.109)
Year FE	✓	✓	✓	✓	✓	✓
Country FE	✓	✓	✓	✓	✓	✓
N	176	176	176	176	176	176
R^2 tot	0.027	0.030	0.345	0.054	0.000	0.414
R^2 within	0.539	0.404	0.153	0.706	0.693	0.095
R^2 between	0.069	0.063	0.366	0.049	0.083	0.504

Country-clustered standard errors in parentheses. * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$
Source: own analysis.

Table 18. Panel FE estimates developing countries for Group 1 – Handling operations/Machine tending

	(1)	(2)	(3)	(4)	(5)	(6)
DEP. VAR.	ln_lf	ln_basicpop	ln_mediumpop	ln_advpop	ln_advbasic	ln_wage
ln_robot	-0.025	0.085	-0.116	-0.472	-0.558	0.174*
	(0.029)	(0.060)	(0.138)	(0.549)	(0.604)	(0.085)
Year FE	✓	✓	✓	✓	✓	✓
Country FE	✓	✓	✓	✓	✓	✓
N	64	64	64	64	64	64
R^2 tot	0.202	0.000	0.038	0.015	0.019	0.355
R^2 within	0.352	0.576	0.190	0.207	0.253	0.765
R^2 between	0.252	0.000	0.039	0.002	0.001	0.357

Country-clustered standard errors in parentheses. * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$
Source: own analysis.

For the OECD countries, we find a statistically significant correlation between robot density and “basicpop”, which is the part of population with a basic education, and “mediumpop”, which is the part of population with intermediate education.

Instead, the result shows a statistically significative (at the 10% level) correlation between robot density and average wages for the developing countries. This means that a 10% increase in robot density corresponds to a 2% increase in the level of monthly wages.

Table 19. Panel FE estimates OECD countries for Group 2 – Welding and soldering

	(1)	(2)	(3)	(4)	(5)	(6)
DEP. VAR.	ln_lf	ln_basicpop	ln_mediumpop	ln_advpop	ln_advbasic	ln_wage
ln_robot	0.020**	0.062	0.023	-0.015	-0.077*	0.106
	(0.007)	(0.045)	(0.027)	(0.025)	(0.044)	(0.084)
Year FE	✓	✓	✓	✓	✓	✓
Country FE	✓	✓	✓	✓	✓	✓
N	176	176	176	176	176	176
R^2 tot	0.003	0.046	0.072	0.040	0.000	0.043
R^2 within	0.553	0.377	0.045	0.706	0.701	0.086
R^2 between	0.005	0.125	0.085	0.003	0.062	0.037

Country-clustered standard errors in parentheses. * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$
Source: own analysis.

Table 20. Panel FE estimates developing countries for Group 2 – Welding and soldering

	(1)	(2)	(3)	(4)	(5)	(6)
DEP. VAR.	ln_lf	ln_basicpop	ln_mediumpop	ln_advpop	ln_advbasic	ln_wage
ln_robot	-0.000	0.096	-0.134	-0.637	-0.734	0.217*
	(0.035)	(0.060)	(0.188)	(0.814)	(0.860)	(0.106)
Year FE	✓	✓	✓	✓	✓	✓
Country FE	✓	✓	✓	✓	✓	✓
N	64	64	64	64	64	64
R^2 tot	0.000	0.067	0.095	0.071	0.000	0.169
R^2 within	0.295	0.555	0.177	0.205	0.250	0.751
R^2 between	0.000	0.094	0.098	0.057	0.012	0.136

Country-clustered standard errors in parentheses. * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$
Source: own analysis.

Regarding the welding and soldering robot application, we find a statistically significant correlation between robot density and "labour force", which is the part of population with 15 or over years old that are currently employed and people who are unemployed but seeking work as well as first-time jobseekers, and "advpop", which is the part of population with advanced education for the OECD countries.

For the developing countries, the result is a statistically significative (at the 10% level) correlation between robot density and average wages. Again, a 10% increase in robot density corresponds to a 2.2% increase in the level of monthly wages in a country.

Table 22. Panel FE estimates OECD countries for Group 6 – Other

	(1)	(2)	(3)	(4)	(5)	(6)
DEP. VAR.	ln_lf	ln_basicpop	ln_mediumpop	ln_advpop	ln_advbasic	ln_wage
ln_robot	-0.002	0.021	0.045**	0.019	-0.001	0.086
	(0.007)	(0.019)	(0.016)	(0.014)	(0.028)	(0.060)
Year FE	✓	✓	✓	✓	✓	✓
Country FE	✓	✓	✓	✓	✓	✓
N	176	176	176	176	176	176
R^2 tot	0.001	0.006	0.289	0.102	0.014	0.506
R^2 within	0.505	0.340	0.229	0.713	0.679	0.100
R^2 between	0.013	0.072	0.312	0.213	0.162	0.660

Country-clustered standard errors in parentheses. * $p < 0.1$, ** $p < 0.05$, *** $p < 0.0$
Source: own analysis.

Table 21. Panel FE estimates developing countries for Group 6 – Other

	(1)	(2)	(3)	(4)	(5)	(6)
DEP. VAR.	ln_lf	ln_basicpop	ln_mediumpop	ln_advpop	ln_advbasic	ln_wage
ln_robot	-0.004	0.025	-0.022	-0.093	-0.119	-0.002
	(0.006)	(0.019)	(0.029)	(0.116)	(0.131)	(0.026)
Year FE	✓	✓	✓	✓	✓	✓
Country FE	✓	✓	✓	✓	✓	✓
N	64	64	64	64	64	64
R^2 tot	0.102	0.014	0.023	0.008	0.001	0.025
R^2 within	0.301	0.535	0.155	0.183	0.224	0.692
R^2 between	0.292	0.041	0.033	0.004	0.107	0.789

Country-clustered standard errors in parentheses. * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$
Source: own analysis.

We find a statistically significant (at the 5% level) correlation between robot density and "mediumpop", which is the part of population with intermediate education for the OECD countries.

For the developing countries, it's not highlighted any statistically significant correlation.

At the end, the final findings are that robots do not destroy or stimulate total employment, meaning that there is not any impact of the variable evaluated or that are present some compensation mechanisms.

In the three-way fixed effects regressions, any statistically significant result is emerged. Looking instead the impact of the different groups of robot's applications, it's highlighted a significative relationship between robot density and average wages for the developing countries. If average wage level is raised there, companies tend to replace them with robotic installations.

The OECD countries in this study are 22: Austria, Belgium, Canada, Czech Republic, Denmark, Finland, France, Germany, Hungary, Italy, Mexico, Netherland, Norway, Poland, Portugal, Slovakia, Spain, Sweden, Switzerland, Turkey, United Kingdom, United States. The results suggest that the investments in robotics derived from an increase in employment, not an increase in wages as before. This can suggest that in developed countries companies that employ more people, maybe for increasing of productivity or because it's needed more qualified and specific competences, will introduce many robots.

In developing countries, which in this analysis are 8, Brazil, China, Indonesia, Romania, Russian Federation, Singapore, Thailand and Vietnam, is resulted a strong negative relationship between robot density and labour force and a positive relationship between wages and robot density. The increase in labour costs generates an increase in robots' installations. This effect can be explained in two different ways, as already introduced previously: multinationals enterprises are relocating in these countries changing the global value chains of employment, because in these countries the demand for work increase, the same the cost of labour and the wages, increasing the installation of robotics. But this phenomenon creates risks of displacement of employees in these least developed countries.

Also, in this investigation the applications of the Group 1, Handling operations/Machine tending, of the Group 2, Welding and soldering, and of the Group 6, Other have resulted more meaningful than others (Dispensing, Processing, Assembling and Disassembling). The reason of this result, that only these three applications have an impact, could be that these three robotics applications require more specialized and qualified technicians than are involved in the work of those robots. The found more significant applications, in fact, are related to those kinds of robots than make a more strenuous work than the others because involved in processes than put them in contact with particular materials and high voltage electricity, so probably they need specific maintenance and more frequent intervention of people. The robots of application of Group 1 and Group 2, in addition, are bigger and more complex than the others, generating a higher need of control.

CHAPTER 5 – POLICIES FOR ROBOTIZATION AND FUTURE TRENDS

Robotization is changing the employment dynamics and the ways of work. Lots of variables are influenced by the introduction of robots because this innovation is destabilizing entire industries and people lives. Companies and workers are not the only impacted by this revolution but, also, the governments and the policy systems will have consequences. Even if, in the past, there have been other technological revolutions, this one seems to be different because these new technologies are acquiring and replicating cognitive and sensory capabilities which were characteristics just related to humans, distinguishing factor between them and machines.

This wave of changes, due to recent robotization and automation developments, is not still clear which results will cause and which dynamics will create, if the employment will be impacted negatively or positively, if the wages will increase or decrease or if the companies will have advantages or disadvantages by the replacement of people with robots.

Policy makers in some countries, following the idea that the future increase of robotization into companies will not be followed by enough employment for displaced people and the new workers, are thinking to introduce some new taxation policies in order to contrast the losses due to this technological evolution.

The tax systems, in the most advanced countries, is based on labour income; in OECD countries around 50% of all tax revenues in 2015 derives from individual income taxed or social insurance taxes. In United States, the tax revenue from human effort is also heavier because, in 2015, the 64,2% of all tax revenue came from individual income taxes or payroll taxes.

In this scenario, firms that automate avoid a lot of taxes and payments just substituting human workers with robots. From this point of view, robotization has more tax advantages because companies don’t have to pay employee and employer wage taxes levied by government and local taxing authorities. In addition, there are indirect incentives for automated workers because there are indirect taxes that levy on goods and services like the VAT that fall marginally on the employer, because worker salaries and retirement benefits must be increased proportionally to offset the indirect taxes.

The policies of government should change in order to modify this paradigm because the phenomenon of robotization and automation is inevitably growing, and the consequences will impact the world and people under different points of view. Companies in order to be enough competitive in the market look how to reduce their expenses and increase profits and the governments, at the other side, should reform the rules in order to incentive companies to continue to produce in their countries and protect employees from displacement.

In the recent years, some governments have started to introduce or, at least, to consider a robot taxation. In the February of 2017, the European Parliament have proposed to impose a "robot tax" on companies' owners of robots to fund support for displaced workers, but it was rejected. In August of 2017, South Korea introduced some tax incentives limitations for automated machines. The Korean companies, nowadays, can deduct from 3 to 7% of an investment in automation tools from their corporate taxes, reducing of 2 percentage points the deduction rate. This taxation, from 2017 to 2021, have demonstrated an effective reduction of investments in robotics.

Candidates for mayor in San Francisco or political candidate in Chicago have already proposed to introduce taxation on Artificial Intelligence and robots, and also, people like Bill Gates, Elon Musk or Stephen Hawking spoke about a "moderate tax on robots" as a natural component of a policy to address rising inequality.

The main object should be, at least, to make neutral the tax system between human workers and automated workers. This, however, require the consideration of international regimes that can be more advantage for companies, so should be created an automation-neutral tax system.

One first idea is to disallow the corporate tax deductions for capital investments that give rise to the automation tax benefit. Reversing the system and accelerating or timing deductions or indirect tax benefits. Another option is to impose a "robot tax" depending on the amount of employees displaced by machines in every company. A similar system is present in many states where the employers have to pay an unemployment insurance based on their ratings, if a company fires more people, it pays more for this insurance. However, this option can generate a negative impact in terms of international tax competition and it's a system that does not consider employees.

Moreover, another possibility is to incentive companies with tax advantages for employment human workers for each category of tax benefit. Moreover, companies that produce goods or services without using human work can be taxed more.

There are still many challenges in this field because this topic is deeper than "unemployment caused by robot". First of all, countries revenues and level of employment is not just related to automation, but there are also political choices that influence those elements. Imposing taxation on automation and robotization could do not solve the problems and disincentivize innovations and research. In addition, different tax systems around the world could generate dislocation of companies in other countries. In order to introduce robots' taxes must be clear the allocation between robot-generated and non-robot-generated income and tax just the part interested from the automation. Moreover, the final consumers must not have advantages to buy goods or services abroad or in other markets.

To the other side, automation and robotization don't only impact the governments, but also the rights of workers. Many social protections are related to the employment status of the people and employees have struggled for long time in order to raise labour standards, expand employee rights and benefits and improve the enforcement of these legal entitlements.

An example is the health insurance in the United States that many people can own just because they are employed. Companies can see advantages in substituting people with machines because they have less expenses related to the employees but, in this scenario, human workers would lose this important insurance and the States would increase losses deriving from companies and should manage a situation where people can't be cured because can't afford it. The governments, in order to protect their citizens, should introduce reforms able to redistribute the expenses of the healthcare insurance between companies and human workers, of all the categories, from the full-time, to the part-time and the freelance workers, in order to maintain the employment status and guarantee health. Helping people with a better coverage of the healthcare insurance that can be transfer through different works and different companies and incentivize a rational replacement where substituted people can be employed in different functions and receive the adapt training in order to be able to continue to work. A similar example is related to those benefits that allow employee to take a period off the work for the care of children or elders relatives.

Some companies, anyway, can take advantages from the replacement, so an alternative could be to transfer the costs of social benefits in a different tax base, no more related to the employment status but related to some other variables in order to redistribute better the payments from wealthier taxpayers towards ordinary taxpayers.

For some scholars a new system should be to decouple these rights from employment by giving a universal minimum wage to all through proportional taxation.

The paradigm must be rethink in order to disincentivize a massive substitution of human workers with machines, do not block the innovations and the technological research, do not make governments lose many revenues and delivering basic social entitlements to people. New policies should balance progressive taxations for the different wealth levels in order to reduce inequality and programs of subsidies with the purpose of enabling people to take time off the work to have more time for the care of the children or elders, time to learn and train new skills for the developing world of labour and subsidiarize more free time, companies will employ also more workers.

The “robot tax” would generate revenues for the governments, but it can’t be the only policy reform to introduce to face up all the changes deriving from this technological revolution.

Furthermore, governments should improve investments in human capital, education and training, and in skills, which are necessary drivers to cope with these technical advances and get the most out of technologies. New technologies and robotics will make many tasks and applied techniques obsolete, affecting the professionalism of workers, making effective training and lifelong learning services essential. New skills requirements will be needed, particularly those of a specialist and transversal nature (soft skills: leadership, team building, creativity, etc.). This will require a rethink, if not an overhaul, of the entire education and training system, as well as a re-literacy of adults, who are under pressure from the gap that will be created between the speed of change and the speed of learning, to make them increasingly compatible with this technological progress. Even more important will be the relationship between the education system and the business world, and the role of placement offices in schools and universities, as well as all other instruments for dialogue with the territories and their economies.

Other actions will have to be taken on social security policies, and on working hours, time and methods. The idea of the labour market, and the concept of work itself, will no longer be what we understand today. These models, which moved in a dynamic market, will be affected by new technologies and robotics that will increase this dynamism to exponential levels. The types of contracts will change and flexible forms of work will be replaced by fixed-term or more flexible ones, creating situations in which people's negotiating skills will be tested by the constant changes in employment relationships and employers, with the relative risk of not being able to move at the pace that the market will impose on them, being crushed from an income and psycho-social point of view.

The significant changes that new technologies will bring about at the level of business organisation will require a new labour market model based on a well-functioning network of labour services, with strong governance at local and national, if not transnational (EU level).

At the end, any country have a perfect policy system able to guarantee benefits and profits for companies, for employers and employees and for the government managing the phenomenon of robotization because the process is still in progress, but those of the ideas previously reported could help policymakers to rethink the policy paradigm in order to balance the different interests involved.

CONCLUSION

Technological innovations have changed the world. The First Industrial Revolution was at the mid-1700 and, after that, other two succeeded. In this period another revolution is happening, and many things are changing. Technologies like 3D printer, augmented reality, virtual reality, artificial intelligence and IoT (Internet of Things) systems are accused of having changed radically lots of different objects with which people interact every day.

Analysing those concepts in the industrial sphere, companies are introducing innovative technologies in order to be competitive in the market implementing, especially, robots and automation systems. The impact of those innovations on employment dynamics within companies and on government systems around the world is not still clear.

The effects of technological innovation on labour depends on several aspects such as labour proficiency, structure of labour market, employment structure within companies.

The debate is still open and there are different points of view from scholars on this topic from the more pessimistic to the more optimistic.

This elaboration has the purpose to understand and analyse this phenomenon conducting a cross-country analysis of 30 countries, developing and developed ones, on the period 2011-2018.

We have assessed the impact of some task-aggregated automated machines on employment dynamics considering different variables. In particular, if the introduction of robotization impacts the labour force, the worker skills determined by the educational level, divided in the three level, basic, intermediate and advanced, and wages. The aggregated groups of robots' applications used were six: Handling operations / Machine Tending, Welding and soldering, Dispensing, Processing, Assembling and disassembling and Others.

The study firstly focuses on the investigation of two in-depth correlations: one regarding the industrial robots' applications, which considered individually, demonstrate more specific correlation relationships between the variables and, secondly, the impact in two groups of different countries, developing and OECD.

The main results from the first analyses are that is present a significative positive correlation between wages and the introduction of robots within companies. From the company's point of view the increase of wages means higher cost of labour, that boosts companies to invest more in automation and robotization because, in this way, after an initial investment the employers don't have to manage an increase of the cost of labour. At the other side, an increase of wages can mean that companies are paying more the people and are employing more qualified and professionals, like engineers or programmers, people with specialized skills that require higher salaries. Moreover, increase of cost of labour can derive from higher productivity requiring more employees. In the eight years considered for the 30 countries the increase of wages has boosted the introduction of the industrial robots within companies for reasons of costs and technological improvements that employers have to consider in order to be competitive in the market.

These findings reveal that the robot's growth doesn't stimulate wages and employment but, on the contrary, an increase in labour costs pushes companies to invest in robotization. The increase of labour cost can be caused, for example, by relocations in developing countries of multinationals companies, which generates an increase of labour demand and wages, disincentivizing local companies to pay more the workers that can be substituted by robots. The result on employment can suggest that there is no relationship or there are compensation mechanisms at the country and / or sector level that balance the values. For example, the reduction of employment in manufacturing sector because of the introduction of robotization is offset by the increase on employment of services sector.

The second part of the first analysis considers each industrial robot's application individually resulting that the increase of wages is explained from just three groups of application, in particular from Group 1 (Handling operations/Machine tending), Group 2 (Welding and soldering) and Group 6 (Other). These three groups of specific robotics applications explain that the increase of 10% in wage is correlated with an increase of the 2% of robot density in the 30 countries for the eight years considered. The reason of this result, that only these three applications have an impact, could be that these three robotics applications require more specialized and qualified technicians or that those specific robots require more control and maintenance, so more employees involved in these processes.

The second analysis, instead, distinguishes from the previous panel of 30 countries, the developing countries and the OECD countries and tries to explain how the variables impact differently in these two specific areas, characterized by a different level of development under many points of view.

In developing countries, which in this analysis are 8, Brazil, China, Indonesia, Romania, Russian Federation, Singapore, Thailand and Vietnam, results a negative correlation between robot density and labour force, determining that the introduction of robots decreases the total employment of those countries. Moreover, also results a strong relationship between robot density and wages. The increase in labour costs generates an increase in robots' installations. Multinational enterprises relocate on these countries and automatize or robotize causing high risks of unemployment and displacement of jobs. This is impacting, in addition, the global value chains because in developing countries like China and Vietnam are installing always more robots because the costs of labour have risen in those countries.

In the OECD countries the findings demonstrate a significative positive correlation between robot density and the variables related to the intermediate and advanced level of education. This means that in the developed countries the increase of robotization generates an upgrade in the educational levels, with people that learn more skills and more competences in order to be more specialized and face up the technological transition. In addition, results a significative positive correlation from labour force to robot density. In those countries has not been highlighted any correlation with the wages. The results suggest that the investments in robotics derived from an increase in employment, not an increase in wages as before.

As before, the analysis regarding the specific robot applications have demonstrated that the industrial robots related to Group 1, Handling operations/Machine tending, to Group 2, Welding and soldering, and to Group 6, Other are the ones that effectively are correlated with the increase of labour force, and consequently of the robot density. Those robots' application results more meaningful than others (Dispensing, Processing, Assembling and Disassembling).

The results demonstrate, at the end, that the impact of robotization and automation within companies is not so disruptive as has usually imagined. Changes in employment dynamics, like increasing of wages, has increased the use of those technological tools.

Moreover, there are difference to consider between countries that are already developed and developing ones, because the OECD countries are positive impacted by robotization, instead the developing ones are negatively impacted from this phenomenon.

Policymakers have an important role in this sense, in order to disincentivize a massive substitution of human workers with machines, do not block the innovations and the technological research, do not make governments lose many revenues and delivering basic social entitlements to people. The paradigm must be rethought investing, in addition, in human capital, education and training, and in skills, actions for social security policies, for better management of working hours, time and methods and with taxation more based on the progressive level of wealth of people, instead that their employment status or income level.

The object should be how to supply the required skilled people with the right education and training to match the demand for diversified jobs positions of the future.

The challenge is to guarantee benefits and profits for companies, employment and work for employers and employees and income for the governments managing at the best the phenomenon of industrial robotization and automation because the process is still in progress and the final consequences are not still predictable.

Appendix

Robustness test 1, where the value equal to 0 are not substituted with a minimum value like 0.01, losing in this way part of observations. For this reason, the observation are less (7542).

Table A1: Robustness test 1: dropping observations where *RD*=0

	(1)	(2)	(3)	(4)	(5)
DEP. VAR.	ln_lf	ln_basicpop	ln_mediumpop	ln_advpop	ln_advbasic
ln*RD*	0.000	0.001*	0.000	-0.000	-0.000
	(0.000)	(0.001)	(0.000)	(0.001)	(0.000)
Country FE	✓	✓	✓	✓	✓
Year FE	✓	✓	✓	✓	✓
App FE	✓	✓	✓	✓	✓
N	7,542	7,542	7,542	7,542	7,542
R^2	0.999	0.997	0.994	0.917	0.919
MeanVIF	1.78	1.78	1.78	1.78	1.78
Max VIF	2.02	2.02	2.02	2.02	2.02

Country-clustered standard errors in parentheses. * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$
Source: own analysis.

Robustness test 2, represents the test using ln_robot = ln(robot_density+1), adding 1 to value of robot density. The total observations, as in the panel, are 9360.

Table A2: Robustness test 2: ln*RD* = ln(robot_density+1)

	(1)	(2)	(3)	(4)	(5)
DEP. VAR.	ln_lf	ln_basicpop	ln_mediumpop	ln_advpop	ln_advbasic
ln*RD*	1.354	8.070	-7.893	-16.280	-24.349
	(1.534)	(7.537)	(4.922)	(16.941)	(20.297)
Country FE	✓	✓	✓	✓	✓
Year FE	✓	✓	✓	✓	✓
App FE	✓	✓	✓	✓	✓
N	9360	9360	9360	9360	9360
R^2	0.999	0.997	0.993	0.910	0.919
MeanVIF	1.80	1.80	1.80	1.80	1.80
Max VIF	1.94	1.94	1.94	1.94	1.94

Country-clustered standard errors in parentheses. * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$
Source: own analysis.

Both these Robustness Test demonstrate that the is are not statistically significative correlation between variables.

REFERENCES

ACAMPORA, C., 2021. *Website [online]. Smart factory: cos'è, caratteristiche e vantaggi,* Internet 4 Things. Available on: https://www.internet4things.it/smart-manufacturing/smart-factory-cose-caratteristiche-e-vantaggi/

ABBOTT, R., BOGENSCHNEIDER, B., 2018. *Should Robots Pay Taxes? Tax Policy in the Age of Automation*, Harvard Law & policy review, Vol. 12, pp. 145-175.

ACEMOGLU, D., RESTREPO, P. 2017. *Robots and Jobs: Evidence from US Labor Markets,* National Bureau of Economic Research. DOI: 10.3386/w23285

ARNTZ, M., T. GREGORY, U. ZIERAHN, 2016. *The Risk of Automation for Jobs in OECD Countries: A comparative Analysis,* OECD Social, Employment and Migration Working Papers, No. 189, OECD Publishing, Paris. Available on: http://dx.doi.org/10.1787/5jlz9h56dvq7-en

ASHTON, T., BARBONE, D., 1998. *La rivoluzione industriale (1760-1830),* Laterza.

AUTOR, D.H., ET AL., 2003. *The Skill Content of Recent Technological Change: An Empirical Exploration*, The Quarterly Journal of Economics, pp.1279-1333.

AUTOR, D.H., ACEMOGLU, D., 2011. *Skills, Tasks and Technologies: Implications for Employment and Earnings,* Handbook of labor economics, Vol. 4, pp. 1043-1171.

BATTILOSSI, S., 2002. *Le rivoluzioni industriali,* Carocci, Roma.

BEKHTIAR, K., BITTSCHI, B., SELLNER, R., 2021. *Robots at Work?,* WIFO Working Papers. Available on: https://www.wifo.ac.at/wwa/pubid/69212

BESSEN, J., 2015. *How Computer Automation Affects Occupations: Technology, Jobs and Skills,* Boston Univ. School of Law, Law and Economics Research Paper No. 15-49.

BESSEN, J., 2019. *Automation and jobs: when technology boosts employment*, Economic Policy, 34(100), pp. 589-626. DOI: 10.1093/epolic/eiaa001

BOWLES, J., 2014. *Website [online]. The computerisation of European jobs,* Bruegel. Available on: https://www.bruegel.org/2014/07/chart-of-the-week-54-of-eu-jobs-at-risk-of-computerisation/

BRYNJOLFSSON, E., MCAFEE, A., 2015. *La nuova rivoluzione delle macchine. Lavoro e prosperità nell'era della tecnologia trionfante,* Feltrinelli.

BRYNJOLFSSON, E., MCAFEE, A., 2018. *The second machine age. Work, Progress, and Prosperity in a Time of Brilliant Technologies,* The Business Source. Available on: http://ebsp.s3.amazonaws.com/pdf/secondmachineaget.pdf

CHIACCHIO, F., PETROPOULOS, G., PICHLER, D., 2018. *The impact of industrial robots on EU employment and wages – A local labour market approach,* Bruegel. Available on: https://www.bruegel.org/wp-content/uploads/2018/04/Working-Paper_02_2018.pdf

CANNA FRANCO, 2021. *Website [online]. Tre milioni di robot nelle fabbriche di tutto il mondo: la robotica industriale supera la pandemia e torna a crescere.* Innovation Post. Available on: https://www.innovationpost.it/2021/10/28/tre-milioni-di-robot-nelle-fabbriche-di-tutto-il-mondo-la-robotica-industriale-supera-la-pandemia-e-torna-a-crescere/

CARBONERO, F., ERNST, E., WEBER, E., 2020. *Robots Worldwide: The Impact of Automation on Employment and Trade*, Beiträge zur Jahrestagung des Vereins für Socialpolitik 2020: Gender Economics, ZBW - Leibniz Information Centre for Economics, Kiel, Hamburg. Available on: http://hdl.handle.net/10419/224602

CASELLI, M., FRACASSO, A., SCICCHITANO, S., TRAVERSO, S., TUNDIS, E., 2021. *Stop worrying and love the robot: An activity-based approach to assess the impact of robotization on employment dynamics,* INAPP Working Paper, No. 67, Roma.

CIRILLO, V., RINALDINI, M., STACCIOLI, O., VIRGILLITO, M.E., 2020. *Technology vs. workers: the case of Italy's Industry 4.0 factories*, Structural Change and Economic Dynamics. DOI: https://doi.org/10.1016/j.strueco.2020.09.007

COASE, R.H., 1937. *The nature of the firm,* Economica, Vol. 4(16), pp. 386-405.

COVEY, S., 2004. *The 8th Habit,* Free Press, New York, pp.12-17.

DANIELE, V., 2008. *La crescita delle nazioni: fatti e teorie,* Rubettino, chapter 2.

DAUTH, W., ET AL., 2021. *The adjustment of labor markets to robots,* Journal of the European Economic Association, oxford University Press. DOI: 10.1093/jeea/jvab012.

DE VRIES, G.J, ET AL., 2020. *The rise of robots and the fall of routine jobs*, Labour Economics, Vol. 66. DOI: https://doi.org/10.1016/j.labeco.2020.101885

DOTTORI, D., 2021. *Robots and employment: evidence from Italy*, Springer Nature Switzerland AG. DOI: https://doi.org/10.1007/s40888-021-00223-x

ESTLUND, C., 2018. *What Should We Do After Work? Automation and Employment Law*, The Yale Law Journal, pp. 257-325.

FONTANA, R., 2013. *Complessità sociale e lavoro,* Carocci, Roma.

FREY, C., OSBORNE, M. 2013. *The future of employment: How susceptible are jobs to computerisation?,* Technological Forecasting and Social Change, Elsevier, Vol. 114(C), pp. 254-280. DOI: 10.1016/j.techfore.2016.08.019

GHOBAKHLOO, M., 2018. *The future of manufacturing industry: a strategic roadmap toward Industry 4.0,* Journal of Manufacturing Technology Management, Vol.29, No. 6, pp. 910-936. DOI: https://doi.org/10.1108/JMTM-02-2018-0057

HUDSON, P., 1995. *La rivoluzione industriale,* Il Mulino, Bologna.

JUNG, J.H., LIM, D.G., 2020. *Industrial robots, employment growth, and labour cost: A simultaneous equation analysis,* Technological Forecasting & Social Change, Elsevier. DOI: https://doi.org/10.1016/j.techfore.2020.120202

KATZ, L.F, MARGO, R.A., 2014. *Technical change and the relative demand for skilled labor: The united states in historical perspective*, in Bouston L.P., Frydman C., Margo R.A., (Eds.), Human capital in history: The American record, University of Chicago Press, pp. 15-57.

KENCEBAY, B., 2020. *Robotization and Welfare Trends in Future,* IntechOpen. DOI: 10.5772/intechopen.93346. Available on: https://www.intechopen.com/chapters/73270

KOVACEV, R., 2020. *A Taxing Dilemma: Robot Taxes and the Challenges of Effective Taxation of AI, Automation and Robotics in the Fourth Industrial Revolution*, The Ohio State Technology Law Journal, 16(1), 182-218.

LABERGE, L., ET AL., 2020. *How COVID-19 has pushed companies over the technology tipping point – and transformed business forever,* McKinsey & Company. Available on: https://www.mckinsey.com/business-functions/strategy-and-corporate-finance/our-insights/how-covid-19-has-pushed-companies-over-the-technology-tipping-point-and-transformed-business-forever

MADDISON, A., 2006. *A millennial perspective,* OECD, Paris-The World Economy, Vol.2.

MANYIKA, J. ET AL. 2017. *A Future that works: Automation, employment, and productivity,* McKinsey Global Institute.

MANYIKA, J. ET AL. 2017. *Jobs lost, jobs gained: What the future of work will mean for jobs, skills, and wages,* McKinsey Global Institute. Available on: https://www.mckinsey.com/featured-insights/future-of-work/jobs-lost-jobs-gained-what-the-future-of-work-will-mean-for-jobs-skills-and-wages

MARCOLIN, L., ET AL. 2016. *Routine jobs, employment and technological innovation in global value chains*, OECD Science, Technology and Industry Working Papers, OECD Publishing, Paris. DOI: 10.1787/5jm5dcz2d26j-en

MARTINELLI, A., MINA, A., MOGGI, M., 2021. *The enabling technologies of industries 4.0: examining the seeds of the fourth industrial revolution*, Industrial and Corporate Change, 1-28. DOI: 10.1093/icc/dtaa060

MIN, X., JEANNE, M.D., SUK HI, K., 2018. *The Fourth Industrial Revolution: Opportunities and Challenges,* Sciedu Press, Vol. 9, No. 2. DOI: 10.5430/ijfr.v9n2p90.

MORAN, M.E, 2007. *Evolution of robotic arms,* Journal of Robotic Surgery, Vol. 1, pp. 103-111. DOI: 10.1007/s11701-006-0002-x

MORRAR, R., ARMAN, H., MOUSA, S., 2017. *Technology Innovation Management Review, The Fourth Industrial Revolution (Industry 4.0): A Social Innovation Perspective,* Academic Publishing, Internet Technology, and Disruptive Innovation, 7(11), pp. 47-56. DOI: http://doi.org/10.22215/timreview/1120

MULLER, C., KUTZBACH, N., 2020. *World Robotics 2020 – Industrial Robots,* IFR Statistical Department, VDMA Services GmbH, Germany.

MURUGESAN, R., 2006. *Evolution of industrial automation,* international Journal of Computer Applications in Technology, pp. 169-174.

OECD, 2017. *Digital Economy Outlook 2017*, Oecd Publishing, Paris.

OECD, 2020. *Digital Economy Outlook 2020*, Oecd Publishing, Paris.

O'ROURKE, K.H. ET AL., 2011. *Luddites, the Industrial Revolution and the Demographic Transition*, The Institute for International Integration Studies Discussion Paper Series. Available on: https://www.usna.edu/Users/econ/rahman/Luddites12June2011.pdf

PESHKIN, M., COLGATE, J.E, 1999. *Cobots,* Industrial Robot, Vol. 26, No. 5, pp. 335-341. DOI: http://doi.org/10.1108/01439919910283722

POLLARD, S., 2004. *Storia economica del Novecento,* Il Mulino.

RAMASWAMY, K.V., 2018. *Technological Change, Automation and Employment: A Short Review of Theory and Evidence,* Indira Gandhi Institute of Development Research, Mumbai.

RIFKIN, J., 1995. *The End of Work: Technology, Jobs and Your Future*, Putnam, New York.

RIFKIN, J., 2011. *La terza rivoluzione industriale,* Arnoldo Mondadori Editore.

SCHLOGL, L., SUMNER, A., 2018. *The Rise of the Robot Reserve Army: Automation and the Future of Economic Development, Work, and Wages in Developing Countries*, CGD Working Paper 487, Centre for Global Development, Washington DC. Available on: https://www.cgdev.org/publication/rise-robot-reserve-army-automation-and-future-economic-development-work-and-wages

SCHWAB, K., 2016. *The Fourth Industrial Revolution,* World Economic Forum 2015.

SHUMPETER, J.A., 1942. *Capitalism, Socialism and Democracy,* Harper & Brothers.

SOUTO-OTERO, M., FREEBODY, S., BROWN, P., 2021. *Technological Change and Labour Substitution: Can Firm Characteristics Shelter Workers Against Automation,* Digital Futures of Work Research Programme, Working Paper 4.

WILLIAMS, R., 1972. *Cultura e rivoluzione industriale. Inghilterra 1780-1950,* Einaudi, Torino.

WORLD ECONOMIC FORUM, 2016. *The future of Jobs. Employment, Skills, and Workforce Strategy for the Fourth Industrial Revolution.*