Università
Ca'Foscari
Venezia

Bachelor's Degree in
Economics, Markets and
Finance

Final Thesis

The Impact of Technological Advancements on the Economy and the Labour Market

With a Special Focus on Robotization and Artificial Intelligence

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Academic Year
2022 / 2023

Index

Abstract

Nowadays the most recent technological trends, like robotics and AI, are expected to transform radically the workplaces by influencing job organization, tasks accomplishment and the type of skills demanded by the labour market. Technological progress has indeed been considered as the main driver of economic growth for a long time. Nevertheless, experts estimate it will also foster a proper revolution of the concept of "working activity" in the long-run. This thesis deals with the evolution of the relationship between technological advancements and society economic systems or labour markets. To provide a thorough view into the issue, the investigation starts from the historical roots of technique to then touch upon more recent economic theories about the likely impact of newly introduced high-tech devices on the economy of nations. The last part is devoted to the policies that governments are called to enforce in order to ease the delicate transition into the era of deep learning algorithms, AI-powered chatbots, cyber-physical systems and high-level machine intelligence.

Introduction

The paper aims at investigating the impact of technological innovations on economic growth and labour market variables such as unemployment and income inequality; with a special focus on AI and robotization as they represent the latest examples of disruptive technologies. Nowadays, the process of digitalization is prompting a multidimensional transformation branching out into different aspects of our lives: not only the economic and productive paradigm is affected, but also the legal set-up, the societal norms, the individual behaviours, and the education system. A new entity, enabled to operate "reasoning" rather than learning by memory, has apparently just been created and it is becoming part of the workforce powerfully. In the literature, scholars adopted diverse economic models to test the macroeconomic impact of the phenomenon, but always through the expansion of a common framework which seems to be depicting it in the most faithful and complete manner: the task-based model, originally introduced by Zeira (1998). It consists in "a model of economic growth and adoption of technologies that replace workers by machines" (Zeira, 1998, p.1092) by means of which the economist was looking for an explanation of trends analogous to the amplification of differences in productivity among countries and the increment of international discrepancy in output per capita. It provided an innovative viewpoint up on which subsequent scholars built their models in the light of newer technological ameliorations. Acemoglu and Restrepo (2017), for example, explored betterments in automation and their effects on low and high-skill workers competing against capital made of machines taking over their tasks. They extended the original task-based model by Zeira to assess the impact on wage inequality ad productivity in the short and long-run. A similar scheme (albeit more empirically oriented) was previously implemented by them to investigate the path of robotization affecting employment and wages in the U.S. labour market. The research revealed a significant consequent reduction of the latter ones. Eventually, since artificial intelligence was catching on, more attention was paid to this field of study. The macroeconomic consequences it triggered were studied by Xu, Yan and Zhiqiang (2019) who developed an interesting theoretical framework (always relying on the original task-based model by Zeira) where they distinguished between alternative and complementary AI and examined the resulting alterations in wages, capital prices, labour and capital shares, and economic growth. They identified two separate outcomes, in the short and long-run respectively, accounting or not for exogenous technology. Although scholars' appraisals may differ and deliver contradictory or disagreeing conclusions, it is overall recognized and proved that the speed of technological growth is increasing. This fact represents the major source of concerns over the population. Given its capacity to self-improve, AI is perceived as leading to a singularity where machine intelligence may surpass human beings and accelerate "as an ever-accelerating pace of improvements cascade through the economy" (Nordhaus, 2015, p.1). Indeed, all the disputes annexed to ChatGPT recent launch brilliantly provide evidence of these worries. In *The History of Technological Anxiety and the Future of Economic Growth: Is This Time Different?* (2015), Mokyr, Vickers, and Ziebarth actually review antecedent technological breakthrough and the fears they elicited questioning if there are differences with respect to present time. In facts, in the past we have already handled the disarming consequences generated by the introduction of a new technology; and noteworthy economists have touched upon the issue by means of several theoretical resolutions. Therefore, in order to successfully include the perspective of the past, the present and of a hypothetical future, the rest of the paper will be organized as follows. The first chapter will be devoted to an historical excursus of technological revolutions: the main inputs and inventions having fostered them, the economic and social transformations arisen, and the opinion of economists having experienced them in first person. In order to do so, the Schumpeterian concept of innovation will be recalled, and the notion of "techno-economic paradigm" introduced by Dosi (1982) will be borrowed in so far as it represents a helpful way to classify historical data according to technological advancements. The five different "big bangs" ("technological improvements initiating the revolution", Perez, 2009, p.8) will be studied from an economic perspective showing ideas and concerns reported by scholars such as Ricardo (1817) and Stuart (1767) for the First Industrial Revolution or Keynes (1931) for the Second one. Previous events should always serve as benchmarks to forecast prospective developments and avoid the repetition of errors. The second chapter will be centred on the analysis of the most recent trends: automation, robotization and artificial intelligence, while in the third, the focus shifts towards foreseeable future scenarios in terms of governmental policies and strategies for a safer and softer implementation of the technology in the society. Formulating an action plan and a coping capacity in case of harmful effects is an essential precautionary principle in order to get prepared to face this delicate period of transition. On the one hand, Grace et al. (2018) collected proofs and comments from a sample of AI experts to estimate the timing of forthcoming AI realizations. Some of such goals have been recently achieved: were scholars' predictions correct? Experts have underestimated the potential of technological upgrading because it has been faster than expected. On the other hand, suggestions were put forward by economists and entrepreneurs to overcome the problem of increasing mechanisation making the labour force shrink. For instance, Bill Gates' proposal of robot taxation was analysed by Guerreiro, Rebelo and Teles (2020) searching for an objective application of the levy through their model. In compliance with their findings, it would be optimal to tax robots until current generations of routine workers retire. Nevertheless, some countries have already started drafting policies dealing with AI and robotization, an overview of them will be presented as well (OECD, 2021). Finally, the last section of the chapter deals with the consequences of technological transition for developing countries. These regions occupy an inferior position with respect to western economies in terms of socio-economic and technical development. Phenomena like robotization may furtherly hamper their lagged GDP growth. The increasing rate of robots' usage in developed nations can have an effect on some low-income countries by surpassing national borders and entailing a strong reduction in the available number of job positions (Faber, 2021).

I. Historical excursus of technological revolutions

Technological advancements (and entrepreneurship) are at the origin of economic growth and, according to Schumpeter (1911), they correspond to the micro drivers of macro phenomena. The scholar made a strong distinction between the concept of *innovation* and that of *invention*, focusing on the former to study the economic and social impact of technology and leaving the latter to the realm of science. He argued that progress and economic growth arise as a consequence of a domino of interconnected innovations, where one pushes the other, finally offering a whole new *trajectory of change* (Dosi, 1982). Hence, technologies are linked and develop together shaping *technology systems* (Freeman, 1992) which represent the output of a previous phenomenon called *technological revolution.* It is a set of correlated radical improvements generating a larger cluster of interdependent technologies (Perez, 2002) where a new great discovery is at the root of a virtuous cycle of smaller changes transforming the way agents interact in markets and societies. This revolutionary breakthrough is defined as a "big bang" opening a cosmos of profitable opportunities and changing labour, production, and resource use profoundly. As of the First Industrial Revolution, Perez was able to observe five of these revolutions in history.

Table 1. Five Successive Technological Revolutions, 1770s to 2000s.

Technologica l revolution	*Popular name for the period*	*Core country or countries*	*Big-bang initiating the revolution*	*Year*
FIRST	The 'Industrial Revolution'	Britain	Arkwright's mill opens in Cromford	1771
SECOND	Age of Steam and Railways	Britain (spreading to Continent and USA)	Test of the 'Rocket' steam engine for the Liverpool -Manchester railway	1829
THIRD	Age of Steel, Electricity and Heavy Engineering	USA and Germany forging ahead and overtaking Britain	The Carnegie Bessemer steel plant opens in Pittsburgh, Pennsylvania	1875
FOURTH	Age of Oil, the Automobile and Mass Production	USA (with Germany at first vying for world leadership), later spreading to Europe	First Model -T comes out of the Ford plant in Detroit, Michigan	1908
FIFTH	Age of Information and Telecommunications	USA (spreading to Europe and Asia)	The Intel microprocessor is announced in Santa Clara, California	1971

Source: Perez (2002)

In recent times, given increasing automation, robotization of production processes and the launch of artificial intelligence-driven tools, one might think that a sixth pioneering era has been unlocked.

For the sake of completeness, the historical path leading to the Fifth technological revolution is put under analysis starting from the origins.

1.1 1771: The Industrial Revolution, J. Steuart, and D. Ricardo

The very first time we can talk about "technology" in history is certainly during the Industrial Revolution, after the introduction of the steam engine by James Watt. Formerly, the economy was agrarian and handicraft, based on the activity of farmers and artisans who employed primitive agricultural tools and techniques. Due to the underdevelopment of production factors, the productivity of workers was scarce, and the economy was mainly aimed at the livelihoods of households; the surplus which could be brought to the market was minimal. Other factors undermining the development of markets were poor transportation infrastructures, characterized by fragmented roads, dirty streets, the absence of enlightenment, and a high mortality rate. Although the birth rate was high as well, the lack of food and proper hygienics were sources of undernourishment and epidemics, preventing demographic expansion. Given the tight correlation between population density and the speed of growth, the population dynamic is a relevant variable of economic growth: the larger the amount of people inhabiting the world, the faster the evolution of the system (Kremer, 1993). Thus, the society was stuck in a condition of equilibrium which was detrimental to progress. Nevertheless, in the second part of the 18th century some co-founding factors shook the system, in particular advancements in agriculture and energy, giving birth to the industry.

Agriculture: improvements were observed in terms of crop rotation or variety, land use and soil health which were fostered by the invention of the seed drill by Jethro Tull around 1701. They resulted in an increase of land yields and a shift towards large-scale commercial farming and market-oriented agriculture.

Energy: coal-fired steam engine was the main driving force of the Industrial Revolution. Steam power was already exploited to pump water out of coal mines, but it was perfected by James Watt's engineering genius. He is considered the father of the steam engine after he patented the "separate condenser" in 1769. Thanks to his experiments and observations, this powerful energy applied to the transportation system and to the industrial production process. The invention of the steam locomotive ushered in the Age of Railways while in the textile sector a new working figure emerged: the labourer.

Industry: the events at the origins of industrialization are several and concurrent, contributing to the expansion of the phenomenon on vast scale. Innovative and efficient metallurgical methods, in addition to the introduction of a new type of furnace, made it possible to craft a larger amount of wrought iron that was useful for machinery and equipment fabrication. The protagonist of the First Industrial Revolution, however, was the textile sector. Actually, British economy was already depending on a strong cotton manufacturing, but it advanced, shifting from small-scale cottage industry to a large and factory-based one, featured by the development of specialized devices. The progress was definitely speeding up. Initially, the new means were based on manpower (the spinning jenny), then on water (the water frame, the spinning mule) and finally on steam, as it was for the power loom and the cotton gin. Indeed, Carlota Perez identifies the invention of the water frame to spin cotton by Sir. Richard Arkwright as the recalled "big bang" initiating the revolution since it heavily transformed the textile techniques. Market and trade were affected, too. The cotton gin fabrication by the American entrepreneur Eli Whitney changed the composition of U.S. exports to England as Americans became the primary producers of cotton (Ennio De Simone, 2014). Therefore, by setting its mill in Cromford village, Arkwright was unconsciously launching the very first business on large-scale and establishing the first factory of the world.

Concurrently to the appearance of more and more sophisticated machines, workers were becoming increasingly concerned. Jobs were changing and craftsmanship suffered a reduction of demand in the "new-born" labour market. Factories productivity was enhanced by the adoption of machinery whereby artistic and manual skills were no more required. This new reality generated an adverse and sometimes aggressive reaction on the part of artisans as the popular Luddite movement phenomenon illustrates (early 19th

century). They were British high-skilled textile workers whose artisanal performance was progressively threatened by the competition of more economic and efficient factory production. They fiercely opposed to mechanization and to the use of knitting frames up to break into factories and destroy means and tools they felt replaced with. (Evan Andrews,2015). However, the establishment of factories did not just worsen past occupations, but also created new professional figures: the new workforce was composed by engineers, mechanics, supervisors, entrepreneurs, and professional accountants. It is the Schumpeterian doctrine of *creative destruction*:

"a process of industrial mutation that incessantly revolutionizes the economic structure from within, incessantly destroying the old one, incessantly creating a new one" (Schumpeter, 1942, p. 83).

In spite of that, scholars of the epoch provided their insights on the issue way before Schumpeter stepped in. For instance, J. Steuart dedicated the XIX chapter of his essay *An Inquiry into the Principles of Political Economy (1767)* to the taking over of machines into manufacturing factories, wondering if this occurrence could go to the detriment of the state or of the population well-being. He was a strong supporter of improvements (which he defined as *of the greatest utility)* boosting the productivity of countries or diminishing the fatigue of labourers. In his view, independently from the *inconveniences* technical progress may provoke, as long as they are borne by the *statesman,* the harm for the working class is temporary and solvable. He compared the introduction of a new machine to the one of peace after a long period of war, which is a commendable achievement despite numerous soldiers becoming unemployed. As the state undertakes their subsistence and reallocation after the war, the same ought to be done for workers after technical advancements. Thereby, the only reason for a prolonging sufferance is a lack of care by the institutions.

Conversely to Steuart, D. Ricardo had a more critical view of the matter. He exhibited his thesis in the thirty-first chapter of the *On the principles of political economy and taxation* (1817) which is titled *On Machinery*. In this passage of the paper, he principally revised his previous declarations in view of a further reflection and a consequent change of mind. Initially, he firmly believed in the positive outcomes provided by the use of machines, arguing they would contribute to the benefit of each social class operating in the market: landowners, capitalists, and the working class. The main source of general advantage for society would be a reduction in prices of commodities accompanied by a productivity enhancement for the same demand as before. However, according to the wage-fund theory, specific and fixed funds exist and are designated to the payment of wages and the acquisition of new machines. Increased investments in technical instruments would reduce the amount of money available to pay salaries of workers and, eventually, the demand for labour. To clarify the theory, Ricardo presented (among others) a historical example where he recalls the adoption of horses as means of production in farming.

"If I employed one hundred men on my farm, and if I found that the food bestowed on fifty of those men, could be diverted to the support of horses, and afford me a greater return of raw produce, (…), it would be advantageous to me to substitute the horses for the men (…)" (Ricardo, 1817, p.477-78).

In his opinion, the only solution is having such an income expansion to let the capitalist afford both men and horses. Nevertheless, the conclusion of the chapter hints at a positive perception of technological improvement on the behalf of the scholar, at least in the long run. Since the implementation of the technology is stepwise, the prolonged increase in productivity would determine rising wages and incomes, hence, savings and accumulations to overcome the initial loss and furtherly boost economic growth. No state should avoid investments in new mechanical devices as the worst mistake with regards to labourers' condition would be the export of machinery to another country. It would make foreign prices more convenient, foreign products cheaper and domestic wages lower.

1.2 1829-1875: From the Age of Stream to the Age of Steel and Electricity

In the second half of the XIX century, after 100 years of betterments in the steam power engine, societies knew a second surge of technical upheaval. The advent of this new era was due to two main factors: firstly, it redefined industries such as heavy chemistry, civil engineering, and the electrical equipment industry; secondly, promoted new inputs like cheaper steel, copper, and cables. The field of infrastructures was highly touched by reason of the fact that electrical networks for illumination and industrial purposes were set (Thomas Edison invented the incandescent light bulb in 1880). In addition to this, the world was becoming more connected: traveling was facilitated by the building of bridges, tunnels, and transcontinental railways, whereas distant communication was marked by the introduction of the telegraph and of a primitive prototype of telephone. The economic system reflected these improvements and modified as a consequence of cost reduction. As Perez is underling, in fact, "the new dynamic introduced in the relative cost structure is an important driver of the emergence of the new techno-economic paradigm. A crucial element in the articulation of a revolutionary constellation is the appearance of a key input that is obviously cheap and getting cheaper (…)" (Perez, 2009, p.15) In the last years of the century, industrial concentration fostered the establishment of the first corporations, characterized by a large amount of capital and workers. By possessing enough financial resources to pursue Research and Development internally, they became the new hub of innovation, providing an extra-stimulus to progress. It is not a coincidence that this period has been remembered as a time of great inventions: artificial dyes and synthetic textile fibres substituted natural ones, Nobel discovered the dynamite while Goodyear's studies allowed for the processing of rubber and Dunlop patented the first tyre. With regard to the production process, well-known phenomena like economies of scale, vertical integration and universal standardization plant their roots in this epoch.

Improved efficiency in the exploitation of resources was perceived and explored by William Stanley Jevons who observed a phenomenon currently defined as the *Jevons Paradox*. The notion lies at the basis of environmental economics by dealing with the ecological consequences of resource consumption. It is considered as a paradox because, contrarily to what the common logic may suggest, when the efficiency of use of an input refines, the consumption of the input does not diminish but augments. In facts, a reduction in the amount of the resource to be exploited for a given use lowers its cost as well, and a fall in costs increases the quantity demanded. The ultimate result is ambiguous, it depends on the one effect which dominates over the other: improved efficiency compared to increasing demand. Yet the second one is more likely to prevail given the additional link between improved efficiency, raising real incomes and higher demand for the input. It is interesting to notice how, by considering labour and technology respectively as the resource and what makes it more productive, the concept may apply to the labour market, too. The outcome would be that an improvement in workers efficiency given by automation causes an increased "consumption" of workers rather than technological unemployment. Anyway, downsides emerging from this interpretation are twofold: in the first place, the reduction in costs would be corresponding to a cutting of wages; in the second place, demand is assumed to be infinitely growing albeit this is not granted. Overproduction may work against the balancing mechanism, letting economic growth slowdown in turn. This is a modern phenomenon, driven by mass production and today's consumeristic society. Its first appearance took place in the subsequent wave of technological revolution: the age of oil, Fordism, and the assembly line.

1.3 1908: The Age of Oil, the Automobile, and the Standardization of Labour

The transition from the third to the fourth technological revolution was sealed in 1908, when the first Model-T car was manufactured in Detroit, Michigan. Actually, the new expansion phase (Kondratieff, 1925) was already perceivable during the *Belle époque* (1896-1918), when oil became the prevailing energy source and people had much faith in the future. Besides, evidence that the pace of development was progressively accelerating is provided by the 20th century's broad variety of historical happenings whereby societies restructured several times. It is sufficient to mention the incredibly quick evolution of the airplane; in 1903 the Wright brothers made the first prototype take off and fly, but just forty years later it played a crucial role in the Second World War. Nevertheless, the main character henceforth will be the automobile. Its invention overturned the business concept, the consumption habits of households, the labour market, and the economic systems of nations. The reason behind such a heavy impact was the new industrial organization conceived by Ford on the basis of Frederick Taylor's studies. They elaborated two strategic patterns of production aiming at an increment in workers efficiency and speed. At that time, recurrent troubles damaging the job quality within factories were the lack of work-flow coordination and of worker's commitment in the performance of tasks. Their innovative structures were based on the scientific division and standardization of labour and on a system of payments by results, both allowing them to save time and money (Annavajhula, 2021). Moreover, the assembly line exploitation in the automotive industry represented one of the first primitive examples of co-operation between men and machine in the sense of technology complementary to labour. The results of this early type of automation were beneficial to employment since simple and rather mechanical tasks let unskilled labour be able to enter the labour market easily. Eventually, the genius of Ford came up with another brilliant intuition: by increasing their salaries, labourers were granted the possibility to purchase an automobile and the consumption of the commodity became widespread through social classes (Ennio de Simone, 2014). Mass-production and mass-consumption took off while population standards of living raised. Europe experienced a demographic increase by 67% (Ennio de Simone, 2014). As a consequence of economic growth and pharmaceutical industry expansion, the attitude of the government towards the human capital changed: the state became more present in the citizens' everyday life. Rising importance was given to medical assistance and primary education. The phenomenon was prompted by Keynes, the economist considered the father of modern macroeconomics. His *General Theory of Employment, Interest and Money* (1936) triggered a proper revolution of the economic thinking, discarding the liberalistic concept of auto-adjusting free market, in favour of government intervention to moderate the aftermaths of economic booms and downturns.

Amongst the copious literature issued by the author, the short essay *Economic Possibilities for our Grandchildren* (1931) provides a commentary on the technological matter, introducing innovative perspectives. In the early part of the 20th century, the society was pervaded by a vague, unpleasant feeling of distrust towards economic growth, which Keynes named *economic pessimism*. The public opinion was commonly persuaded that the epoch of groundbreaking scientific innovation had gone by and there was no chance for further progress. Almost all the relevant challenges had been defeated and expectations of a *decline in prosperity* were solidly installed. Nonetheless, Keynes dissented from this belief, defining it as a "wildly mistaken interpretation of what is happening to us" (Keynes, 1931, p.358-373). To him, the society was simply knowing a moment of transition in between economic periods, but a peculiar and painful one because *changes* were *over-rapid*. Indeed, in modern age the rate of progress had accelerated due to the settlement of the two root causes of a slow growth: "the absence of important technical improvement and the failure of capital to accumulate" (Keynes, 1931, p.358-373).

The situation firstly changed in the 16th century, when the power of accumulation by compound interest recovered, probably as a result of Spanish imports of gold and silver from the New World and the consequent rise in prices. Secondly, in the 18th century science moved forward. And it is exactly in science unpredictable improvement that the source of *technological unemployment* resides. This notion was introduced by the economist for the very first time and it was described as

"unemployment due to our discovery of means of economising the use of labour outrunning the pace at which we can find new uses for labour" (Keynes, 1931, p.358-373).

As we can infer, this new type of unemployment was conceived by Keynes as a temporary worry which, once solved, might drive mankind to the permanent resolution of the economic problem. In fact, humanity has always struggled for subsistence throughout history: by hunting animals, by planting and growing farms to feed one's own family, by traveling the seas in search of treasures and riches, colonizing new countries, emigrating, or investing financial assets. Yet in the light of most recent developments, Keynes concluded that the solution is near and, once it will be attained, the real primary and long-lasting problem of human race, so far hidden behind livelihood concerns, will emerge:

"how to use his freedom from pressing economic cares, how to occupy the leisure, which science and compound interest will have won for him, to live wisely and agreeably and well" (Keynes, 1931, p.358-373).

Initially, it will be challenging adapting to the new lifestyle, given centuries of hard work and sacrifice; a gradual detachment from the working activity will be necessary. This process can be seen as a progressive reduction of hours of work per day, shifting from a

40-hour weekly plan to a 20 or 15-hour one. Countries will be wealthy and the market saturated so that we will not need more. For another time Keynes gave evidence of his foresight in predicting future scenarios since nowadays more and more governments in Europe are evaluating (UK, Spain) or undertaking (Belgium) a measure for the reduction of the working week, extending the days of rest from two to three. In any case, the fact that we are still at the initial phase of the process is pointed out and although it represents the natural evolvement of things, its pace can still be under our control. It will depend on our ability to manage and monitor four different factors: population, science, wars, and the rate of accumulation.

1.4 1950: The Age of Information and the Solow Model

The 20th century is infamously remembered as a time of big wars. Three different conflicts which involved the majority of world countries succeeded each other (World War I, World War II, and the Cold War); while colonies fought for the independence from the European motherland. The world socio-economic set-up resulted completely revolutionised at the end of the century.

From a political point of view, the closing of the century was marked by nations seeking peace and justice. The European Union (1993) and several world organizations like the "United Nations" (1945), the "Organization for Economic Co-operation and Development" (1961) or the "World Trade Organization" (1995) were established with the aim of a peaceful cooperation among states in the pursuit of international normative, economic, and humanitarian objectives.

Economically speaking, two antithetical models dominated the geopolitical scenario of the world: the market economy and the command economy. They mirrored the two counterparties opposing during the cold war. The first economic model, headed by the US giant, was tightly linked to the capitalistic organization of the economic activity. Private ownership of means of production and voluntary exchanges between economic actors constitute its pillars. On the other hand, command economy was featured by a centralized decision-making and monitoring system whereby the government owns land, capital and resources and sets supply and demand for goods. At the time, it was represented by the Soviet Union.

On the technological front, 1971 symbolized a turning point for computer science and the moment when the intel microprocessor was announced for the first time in Santa Clara, California, ratified the beginning of a new technological wave. The coexistence in the same century of world wars and of an exceptionally fast development in science and technology is not casual. The desire to beat the enemy's army and gain competitive advantage in terms of equipment and weaponry has encouraged governments to invest in military technologies. Most of current industrial or everyday technological tools represent the evolution of inventions originally designed to be implemented on the battlefield. Especially during the Cold War's years (1947-1991), the American and Soviet superpowers engaged in a dispute touching all the fields but the open clash. A large number of relevant inventions whose first appearance dates back to this period were conceived for military purposes: the digital photo camera, the microwave, UAVs, computers, lyophilization, the Internet and many others.

This last technological surge was also interested by the spreading of international trade and world digital telecommunications. Countries, in spite of previous century's wars, became more connected owing to the explosion of instant global communications. Technological advancements helped the spreading of a phenomenon of industrial decentralization characterized by firms embracing network structures and by markets becoming segmented and focusing on niches. New devices such as the Internet, electronic mails, e-services, satellites, and high-speed multi-modal physical transport links granted a faster and smoother flow of communication (Perez, 2009). Moreover, to let this newfound supply of technological tools meet an adequate demand, incomes of workers were raised, improving material standards of living consequently. A real revolution of information took place and boosted economic growth dramatically.

The increasing speed of economic growth of the century was noticed and examined by Robert Solow. He proposed a new model of long-run growth, currently defined as the *Solow* or *Growth Model,* in an article published by the MIT Press in 1956. His investigation attempts to assess the main determinants of economic growth and the effect of capital accumulation and technological progress on a nation's total output of goods and services (Mankiw, 2010). His economic theory focuses on the aggregate output function. By assuming constant returns to scale and diminishing returns with respect to output factors, he was able to explain the dynamics of output and capital stock in the long-run, which are given by the following equation:

$$\frac{K_{t+1}}{N} - \frac{K_t}{N} = sf\left(\frac{K_t}{N}\right) - \delta\frac{K_t}{N} \tag{1}$$

where $\frac{K_{t+1}}{N} - \frac{K_t}{N}$ is the variation of capital stock per worker over time; $sf\left(\frac{K_t}{N}\right)$ is savings (investments on capital) per worker and $\delta\frac{K_t}{N}$ is depreciation of capital per worker.

The *steady-state level of capital* represents the condition whereby capital does not vary, hence, the level of capital $\frac{K*}{N}$ at which the two forces affecting it (investments and depreciation) are balanced: the *break-even investment level*.

$$sf\left(\frac{K*}{N}\right) = \delta\frac{K*}{N} \tag{2}$$

The higher the saving rate, the faster the economic growth. But this condition does not hold permanently. There is an optimal level of capital in the economy: the one maximizing consumption, thus, households' utility. It is the *Golden Rule level of capital*, the unique steady-state capital associated with the maximum level of steady-state consumption (the *Golden Rule level of consumption*) and related to the only *Golden Rule rate of savings*. By means of the Golden Rule, Solow was able to observe that, given the convergence towards an equilibrium, sustained economic growth is not yielded by capital accumulation. There must be other forces operating underneath wealth creation. He identified population growth and technological development as such engines. Including population growth in the model makes the new break-even investment level look like:

$$sf\left(\frac{K*}{N}\right) = (\delta + n)\frac{K*}{N} \tag{3}$$

This implies that if the number of workers, total capital and total output are increasing at rate n there is sustained economic growth. Otherwise, GDP per person decreases, which is frequently the case of developing countries.

On the other side, the technological progress accounted for in the model is of *labour-augmenting* type since it enhances the efficiency of workers as if their number increased. A third variable E, representing labour productivity, must be incorporated and multiplied by the number of workers N. The new break-even investment equation includes the rate of population growth n and the rate of innovation g:

$$sf\left(\frac{K*}{N \times E}\right) = (\delta + n + g)\frac{K*}{N \times E} \tag{4}$$

By adding technological progress, once the economy has reached the steady-state, output per worker continuously grows at rate g and rising living standards can be explained.

Table 2. Steady-State Growth Rates in the Solow Model with Technological Progress.

Variable	Symbol	Steady-State Growth Rate
Capital per effective worker	$k = K/(E \times L)$	0
Output per effective worker	$y = Y/(E \times L) = f(k)$	0
Output per worker	$Y/L = y \times E$	g
Total output	$Y = y \times (E \times L)$	$n + g$

Source: Mankiw (2010)

The permanent increase in output per worker makes technological progress be the unique variable able to describe the two phenomena previously cited. Moreover, the rate of growth seems to stay constant over time, predicting convergence of similar economies at a rate of 2% per year. Notwithstanding, it is necessary to mention the fact that the Solow model considers technological advancement as an exogenously-assumed factor, without specifying its sources and origins.

"My purpose was to examine what might be called the tightrope view of economic growth and to see where more flexible assumptions about production would lead a simple model" (Solow, 1956, p. 91).

Newer models, generally labelled as endogenous growth theory, tried to overcome the issue, with a deeper analysis of the effects on unemployment and increasing income inequalities among countries.

II. Economic analysis of current technological trends

Deep learning algorithms, AI-powered chatbots, autonomous vehicles, the metaverse and cyber-physical systems are just several examples of the latest high-tech devices promoted by the technological industry. They constitute the major drivers of transformation of the world's economic systems and their effect on society is triggering debates and concerns. The most frightening attribute is their capability to replace workers in their cognitive proficiencies whereas, in the past, machines took over only strenuous physical tasks. To this end, technology sounded really of labour-augmenting type because the productivity of workers was enhanced without depriving them, most of times, of their factual job. Innovation was helpful towards labourers, their work resulted less burdensome or dangerous despite the potential increase in unemployment. An additional benefit allowed by technical improvement, at least more recently, has certainly been in the firm organizational context. Through fresh job design approaches like job enrichment and job enlargement, people were granted the possibility to expand their range of tasks and combine physical and cognitive skills, offering more stimulating and interactive activities. The eventual harm was threating just the blue-collar class of the workforce. By contrast, the latest patterns of development such as artificial intelligence and robotization spread the menace to highly skilled workers, too. Due to their distinctive capabilities (i.e. machine learning, computer vision and natural language processing), AI-driven machines can reproduce human actions by browsing data and extracting meaningful insights without being programmed. To this extent, they are outperforming humans bounded capacity of conceptualizing hidden relationships within a massive amount of data. Not by chance, Acemoglu and Restrepo (2017) present a task-based model in which both high and low skill workers face the outputs of automation, while Frey and Osborne (2017) alert that 47% of jobs in the US economy may be automated consequently to advances in AI-related fields. Therefore, the questions we aim at answering hereafter will be: did the advent of these new tools open a new tide of technological development? If so, could this wave be comparable to previous ones or there is something intrinsically different which allows James Barrat

(2013) to label AI as "Our Final Invention"? What do economic theories predict about the likely impact on the labour market?

This section will be devoted to the analysis of the contemporary macroeconomic impact of technological advancements. Scholars' findings and economic theories will be collected according to the three most recurrent templates of development: automation, artificial intelligence and robotization.

2.1 Automation

The term "automation" refers to the use of technology and the integration of machines into a self-governing system in order to perform activities minimizing human input. Most frequently it applies in the enterprise context via business process, IT, or network automation, but the elements characterizing it stays the same: a source of power, feedback controls and machine programming (Groover, 2023). The result of its implementation in different contexts has been investigated by several authors. For instance, Dawid and Neugart (2022) tested its implications running some experiments through an agent-based simulation framework where they were able to observe outcomes varying according to the presence or absence of entry barriers. Acemoglu and Restrepo (2017), instead, wanted to explore the different effects occurring when low-skilled or high-skilled workers' tasks are taken over by automated machines.

2.1.1 The different effects of low and high barriers to entry

In Dawid and Neugart (2022), the technological development consequences at industrial level change due to alternative market competitive structures. They chose parameters according to the empirical evidence as well as macroeconomic indicators and ran four stylized experiments (the main findings of two of them are summarized in Table 3). Experiments are meant to capture the most likely dimensions of industrial automation (*Deepening of automation, Labour-augmenting technological advances*, a combination of the two, and a *Shift in tasks*) along with their impact on selected variables: *Total* *output*, *Firm profits*, *Average real wages,* and the *Theil index* which is a measure for wage inequality.

Table 3. Summary of the Main Effects Arising in Experiments (1) and (2) under Homogeneous Firms and Workers.

	Productivity	Reallocation/ Labor demand	Price	Composition	Entry & exit	Total
Deepening of automation (Exp (1)):						
Total output	+	−			+	+/++
Firm profits	+	+	−		−	+/ ~
Ave. real wages		−	+	+	+	−/+
Theil index				−		−/−
Labor augmenting (Exp (2)):						
Total output	+	+			−	++/+
Firm profits	+	−	−−		+	−/ ~
Ave. real wages		+	++	−	−	+/++
Theil index				+		+/+

Source: Dawid, Neugart (2022)

The two experiments of the table differ depending on the one factor whose efficacy is strengthened: capital in Exp(1) or labour in Exp(2). The former touches on machines productivity increment whereas the second experiment is a type of technological change which augments workers' throughput. The total impact on variables fluctuates in compliance with the presence/absence of barriers. The table above presents a set of significant intuitions deriving from the study. For example, the impact of automation on *Total output* holds positive for both experiments, with a slight disparity on account of barriers:

+/++ for Exp(1) indicates a stronger effect without barriers than with a fixed amount of firms in the market.

++/+ for Exp(2) means that in case of labour-augmenting technology the effect is stronger when barriers are present.

In addition to this, the impact on *Average real wages* is always positive for technological development affecting labour, while when high barriers and deepening of automation are experienced simultaneously, *Average real wages* tend to decrease. Hence, a suggested policy to overcome the detriment of real wages could be dampening barriers to entry (see Chapter 3 for more about the policy perspective). Finally, the Theil index has a completely different response in the two cases. It witnesses an increase of inequality for efficiency enhancements of capital and a smoothing of them when the other factor of production is altered.

2.1.2 The different effects of low-skill and high-skill automation

In Acemoglu and Restrepo (2017) there is a distinction between two forms of automation: *low-skill* and *high-skill* one. In both cases they coincide with capital substituting the usual tasks of workers. The difference depends on where activities are allocated along the value chain: at the beginning for low-skilled employees and towards the end for high-skilled ones. The automation effects on the labour market submitted in the model are two: a *displacement effect* and a *productivity effect*.

In the short run equilibrium, profit maximization is achievable if tasks are distributed to factors of production according to their comparative advantage. This implies that whether activities will be performed by humans or machines depends on the most economic option. On the one hand, the *displacement effect* implies the replacement of labour with capital and causes a wage reduction because labour is less required. On the other hand, the *productivity effect* let wages increase because cheaper capital reduces costs of firms and expands their productivity. The growth of economic output eventually makes the demand for all tasks rise together with factors' prices. Since these two effects push towards *opposite directions,* the total impact is ambiguous. To forecast under which circumstance one condition prevails over the other, the authors focused on differences in the costs of factors of production. Comparing rental rate and wages, if the latter exceeds the former in relative terms, the *productivity effect* is weak and the wage rate falls, while when the price of capital is low because of its abundancy, *productivity effect* dominates, and wages increase. Furthermore, another phenomenon named *ripple effects* may take place. It happens when high-skill labour, facing relocation, is forced to accept a lower-level working position, where inferior competences are demanded. Thus, the competition between the two classes of workers increases, furtherly enhancing displacement and wage inequality. Nevertheless, *ripple effects* are given by comparative advantage: when high and low skill workers are perfect substitutes (tasks are interchangeable) they are maximized otherwise they are null. Lastly, the ultimate upshot of *ripples effects* in the short-run is that when they are matched by a weak *productivity effect*, real wages of both factors could be pushed down by rising automated capital.

The long-run version of the model developed by Acemoglu and Restrepo (2017) assumes a constant price of capital (rental rate) with a quantity adjusting accordingly. Findings of the analysis show that in the long-run both low and high skill automation have a positive effect on wages. This fact occurs as a consequence of increasing demand for capital which fosters its accumulation and magnifies the productivity effect. However, the possibility to reduce the wage of the *directly affected factor* still exists because of the *displacement effect*. The policy proposed by Piketty (2014) to solve the issue is "taxing capital", but the authors highlight how this reaction may discourage the accumulation of capital annulling the advantageous effect on labour prices.

2.2 Robotization

The previous paragraph on automation definitions, implications, and characteristics exhibits, the general expression "automation" refers to a broad set of industrial processes exploiting technology to gain productivity. Robotization constitutes one of its branches as it stands for the practice of using specific automated equipment (industrial robots) to carry out human tasks. A commonly accepted definition of "industrial robot" is the one provided by the *International Federation of Robotics,* according to which it is "an automatically controlled, reprogrammable, and multipurpose machine" (IFR, 2014). The main difference with respect to software, hardware or whatever type of device is that it does not need a human operator governing it throughout the execution of tasks. As a matter of facts, recent advancements in artificial intelligence R&D provoked an increase in the quantity of AI-driven robots employed within factories. Acemoglu and Restrepo (2017) acknowledged robotization occurrence and decided to examine into details its economic consequences by providing an empirical framework where the correlation between robots and jobs is tested via regression analysis.

2.2.1 A simple model by Acemoglu and Restrepo (2017)

Firstly, to build a model successfully expositing the impact of robotization on wages and employment, the notion of *commuting zones* is introduced. These zones are the equivalent of local labour markets whose trading interactions alter the "sensitivity of employment and wages to the adoption of robots" (Acemoglu and Restrepo, 2017, p.10). When costs decrease in a commuting zone, other zones' living costs and employment rates reduce, too, for competitive reasons.

The equation representing the demand for labour in a commuting zone c corresponds to:

$$dlnL_c^d = -\sum_{i\in I} l_{ci}\frac{dM}{1-M} - \lambda\sum_{i\in I} l_{ci} dlnP_X + (\lambda-\sigma)\sum_{i\in I} l_{ci} dlnP_Y + dlnY \quad (5)$$

where:

$dlnL_c^d$ is the variation in the demand for labour.

l_{ci} is the share of employment.

M is automation.

λ is the elasticity of substitution between varieties of the same good sourced from different commuting zones.

P_X are the prices for varieties.

σ is the elasticity of substitution across goods produced in different industries.

P_Y are the prices for consumption aggregates of different industries.

Y is the total output of total industries.

Two forces frame the demand: the *displacement effect* (a negative impact working equivalently to the automation model; see Chapter 2, paragraph 1) and the *productivity effect*, functioning through two distinct positive channels: the *price-productivity effect* and the *scale-productivity effect*.

Price-productivity effect: a higher degree of robotization intensifies one industry's output. Hence, labour demand increases.

Scale-productivity effect: labour demand grows subsequently to the expansion of all industries Y_c.

In the previous equation the first term stands for the *displacement effect*, the second and the third for the *price-productivity effect* and the fourth is the *scale-productivity effect.*

2.2.2 Empirical evidence from the U.S. labour market

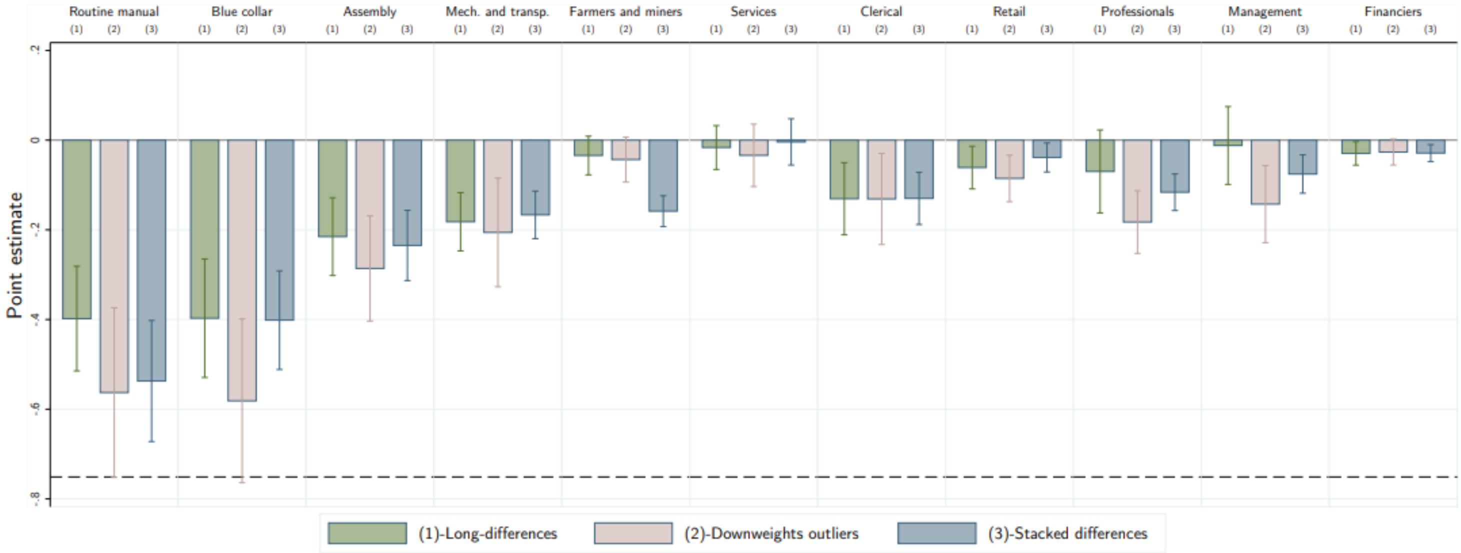
In the second section of the working paper the authors tried to make sense of data collected from the U.S. labour market, looking for a correlation between the incremental use of robots within firms and changes in the labour market elements. The estimated impact is computed by regressing the variation in employment and wages over time on the variable *US exposure to robots* in each commuting zone. This variable is the sum of variations in robots' usage rate for each US industry divided by the industry's baseline employment weighted for baseline employment shares. The aftermath is negative, implying that "one additional robot per thousand workers reduces aggregate employment to population ratio by 0.34 percentage points and aggregate wages by 0.5 percent" (Acemoglu and Restrepo, 2017, p.36). In greater detail, the effect slightly differentiates depending on:

Gender: the impact on employment is larger for men than for women.

Industry: the manufacturing sector is the hardest hit.

Occupation: workers performing routine manual activities (*blue-collar workers, assembly workers, machinists*) are more threatened than managers for which the estimated impact falls down to zero. The following table summarizes the main findings of the analysis grouped by occupation.

Table 4. The Relationship Between the Exposure to Robots and Occupation Employment.



Source: Acemoglu and Restrepo (2017)

2.3 Artificial Intelligence

On March 14, 2023, OpenAi launched the last version of the multimodal large language model GPT-4 ("Generative Pre-trained Transformer"). The software is characterized, like the previous version, by "ChatGPT", a chatbot product by means of which people can interact with the LLM in a direct way. In this last edition, the program informative datasets were magnified in order to increase factual accuracy, reduce the likelihood of generating errors and improve the ability to follow the user's intention (Leggatt, 2023). For the first time normal people, rather than computer scientists or web developers, can exploit artificial intelligence without the need for coding skills, and the properties of the language have amazed users to the point that AI has become a hot topic. People are concerned mainly about its ethical and socio-economic implications.

Despite the numerous challenges entailed by artificial intelligence, the first formal issue arising is related to its definition. Actually, a unique commonly-accepted definition of AI does not exist. For the sake of clarity, this paper refers to the one provided by OECD's AI Experts Group (OECD, 2019) and reported in the working paper about the impact of Artificial Intelligence on the labour market.

"An AI system is a machine-based system that can, for a given set of human-defined objectives, make predictions, recommendations or decisions influencing real or virtual environments. It uses machine and/or human-based inputs to perceive real and/or virtual environments; abstract such perceptions into models (in an automated manner e.g. with machine learning (ML) or manually); and use model inference to formulate options for information or action. AI systems are designed to operate with varying levels of autonomy." (OECD, 2021, p.17)

Studying the phenomenon under an economic perspective, the effects triggered by its implementation touch upon the productivity of countries, altering the level of employment and the distribution of income.

2.3.1 The impact on productivity

Although AI is expected to provide a wide productivity increase on account of the concurrence of lower costs and efficiency betterments, empirical evidence does not support such thesis. The capital-output ratio is not rising, and the cost of capital is not decreasing faster (Nordhaus, 2015). The current lagging of productivity growth is known as *productivity paradox*. It may be due to an overestimation of AI potential. Given the complementary role it takes with regard to other technological advances (automated industrial processes or robots may be AI-driven technologies), there are sufficient grounds to believe it will not lead to a *singularity* in economic growth in the near future. AI cannot open a new technological surge by itself, but it will entail marginal improvements of existing technologies, leading to a modest productivity growth (Gordon, 2018). Furthermore, in the technological industry there is a limited number of incumbent firms owning the technology monopolistically and guiding development. They rely on their market power to block potential entrants via non-disclosure of their technological steps forward. The consequent winner-takes-most dynamic occurring may be another source of productivity slowdown (Brynjolfsson, Rock and Syverson, 2017). Yet productivity growth may also be following the S-curve pattern. This scheme is typical of the learning curve whereby initial laggings are elicited by the necessity to invest in the implementation and restructuring of AI before competition and complementary technologies improvements let acceleration take place (OECD,2021). Assuming this type of development, McKinsey (2018) predicted an impact of AI on productivity of $13 trillion by 2035.

2.3.2 The impact on wages and employment

The economic impact of artificial intelligence has been foreseen by Huang, Hu, and Dong (2019) on the basis of a theoretical framework where two sorts of AI are incorporated into the production function: the *alternative* and *complementary* one. The first category includes autonomous vehicles and 3D printers and tends to reduce the labour share. By contrast, the complementary class (Watson, Siri or ChatGPT) is expected to boost the labour share. The effect on wages is positive because of the lower price of capital. Besides, the results of their analysis highlight one major public concern: AI self-improvement skills might let machine intelligence outperform humans someday. Undoubtedly, there are classes of occupations more likely to be surrogated; it depends on the type of tasks they are featured by. Differently from automation and robotization, AI represents a threat for high-skill workers and white-collar occupations (OECD,2021). In addition to this, the degree of exposure to AI is positively correlated with demographic variables such as education level and age; it increases with the amount of skills, judgement capabilities or accumulated experience required by the job and male-dominated occupations are more prone to the replacement than female-dominated ones (Webb, 2020). However, a large branch of scholars and experts distrusts the eventuality that AI substitutes humans' working activity totally in the future. As the *Polanyi's Paradox* records, a large percentage of roles does draw on tacit knowledge (shared best practices, implicit values, rules of thumb) which is intuitively assimilated by workers and not comprehended by computer programs (OECD,2021).

2.3.3 The impact on inequality

Artificial intelligence may enhance income distribution disparities through two channels: the *surplus earned by innovators* and *the effects on other agents* (Korinek and Stiglitz, 2019).

The first condition is given by the intrinsic nature of consumption technology which is an "information good" featured by non-rivalry (one additional consumer enjoying the good does not decrease the utility of other users) and excludability (you can prevent someone from its consumption). Excludability is the source of innovators' market power and usually it is exerted via intangible assets like intellectual property rights (copyright, trademarks, and patents in particular). Their principal function is providing inventors with exclusive rights over the use or production of their creation in such a way that they can earn an economic benefit from it. Their implementation triggers the increase of monopolists' private surplus and of the deadweight loss all along with the decrease of social welfare. This happens because technological positive externalities derived from the invention cannot be extended to other market agents. Thereby, inequalities arise both in general terms and within the innovators group which is characterized by a highly-skewed distribution of payoffs (Korinek and Stiglitz, 2019).

The other channel works through *pecuniary* and *nonpecuniary* externalities (Korinek and Stiglitz, 2019). The former type of externalities arises from variations in the demand for factors (e.g. wages) altering their prices. Although these externalities are considered *Pareto efficient*, there are two reasons why they create inefficiency in practical terms: due to the presence of additional market imperfections and because redistributive policies to overcome the issue are expensive. On the contrary, *nonpecuniary externalities* are given by changes: in the quantity demanded for a good, in the probability of buying or selling a good or factor and in the probability of being unemployed (Korinek and Stiglitz, 2019).

III. Future patterns of development and policy responses

Inferences drawn in the previous chapter highlight how different technological trends profoundly influence technical improvement implications both on the labour market and in general. For instance, one can observe that, while robotization tend to make low-skill workers worse-off, artificial intelligence, with its ability to replicate human reasoning and language, hits the opposite class of workers: white-collar ones. The final impact on employment is certainly ambiguous, it is based on the ratio between newly-introduced jobs and the ones lost due to automation. A positive ratio would denote the formation of a sufficient number of new professions to limit the unemployment rise. Notwithstanding, experts' opinions diverge in this regard. Wilson, Daugherty and Morini-Bianzino (2017) analysed a sample of companies employing machine-learning systems. They found out that there are at least three different occupations emerging from artificial intelligence progress: *trainers* of AI systems, *explainers* interpreting their outputs and *sustainers* ensuring such systems work properly. Moretti (2012) instead focuses on the *indirect* job creation, outside the technological field. He was able to prove the existence of a large multiplier effect eliciting the establishment of five additional jobs outside the high-tech industry for each new one created within the sector. By contrast, Acemoglu and Restrepo (2020) adopt a less optimistic view, arguing that the expansion of the number of jobs within AI industry will not be enough to cover the loss in other sectors. This phenomenon would generate remarkable income disparities. If so, policymakers will be required to reallocate workers and redistribute welfare. When selecting their measures, they ought to focus on economic effects such as the aggregate production increase, the type of education, skills and tasks demanded by the working activity and the definite disappearing of some jobs. But one additional challenge will appear, because AI consequences on the labour market will trigger unprecedented repercussions. Indeed, although people's fear of being replaced by machines exists from the very First Industrial Revolution, the artificial intelligence development path seems to be different. This disruptive technology is featured by one attribute which has always been exclusively owned by human beings: intelligence. It has been constructed as to mimic humans' wit, combining large datasets with iterative processing and algorithmic training to look for patterns and learn from them via trial-and-error. In doing so, artificial intelligence can solve complex mathematical problems, answer questions, and make predictions. Nevertheless, the risk of reducing human-beings' competitive advantage in the labour market is larger than with robot and other devices.

This last chapter of the thesis will be dealing with hypothetical and actual solutions: strategies theorized by scholars which policymakers may use as frame of reference in the near future and real political or normative responses of governments. Eventually, room will be left to discuss the inequality issue, in particular with regard to developing countries. As Korinek and Stiglitz (2021) stress out, labour-saving, resource-saving, and winner-takes-all dynamics characterizing AI progress undermine the integration recently achieved by emerging economies. What are the forces furtherly enhancing such detrimental tendency? And what types of economic policies would combat them ensuring an inclusive distribution of artificial intelligence benefits?

3.1 Experts' estimates about high-level machine intelligence utilization

The first step towards drafting helpful mitigation policies is having a clear idea of what technological advances consequences may be. The aim is principally pinpointing dangerous effects beforehand rather than solving them once occurred. To this end, Grace et al. (2018) surveyed a sample of 352 machine learning researchers; relying on their into-the-field expertise and assuming no one could be better informed about artificial intelligence development path. They were asked several questions regarding the *timing* of specific AI capabilities and its *superiority* in the fulfilment of human tasks. The scope of their inspection was extrapolating meaningful insights about the effect of high-level machine intelligence (HLMI, when every task can be fully automated) on economic growth, the probability to incur positive or negative outcomes and the enforceable measures to limit the latter. They key findings resulting from the study highlight that:

- The aggregate estimated time required for the arrival of HLMI is of 45 years with a 50% probability.
- Full automation is expected to come within 122 years with a 50% chance.

- Forecasts differ depending on experts' demographic attributes, for instance, Asian researchers predict the AI breakthrough to occur 44 years before North Americans.

To infer such conclusions, respondents were asked individually how much time would have been necessary to attain a selected subset of "milestones" in AI improvement. Milestones correspond to a variety of goals ranging from the generation of songs to surgery. It is worth noticing how machine intelligence can already undertake some of these "tasks". Since collected data dates back to 2016, it is possible to assess the variation from the predictions in the light of recent betterments in large language models technology.

Table 5. AI Milestones and Timing Expectations.

MILESTONE	DESCRIPTION	ESTIMATED YEAR	ACTUAL YEAR
Python Code for Simple Algorithms	Write human-readable Python code to implement simple algorithms.	2024	2023
Answer Open-Ended Factual Questions via Internet	Answer "easily Googleable" factual questions posed in natural language.	2026	2023
High School Essay	Write an essay for a high school history class that would receive high grades and pass plagiarism detectors.	2026	2023

Source: Grace et al. (2018)

The average estimated time required for AI to accomplish the aforementioned tasks was around ten years. However, the latest version of the generative pretrained transformer GPT-4 is perfectly able to perform them and via its chatbot ChatGPT everyone is granted the possibility to give a try for free. The proof of an acceleration in AI progress is quite evident.

3.2 Robot taxation: a hypothetical solution

On February 2017 Bill Gates defined robot taxation as a "good way to at least temporarily slow the spread of automation and to fund other types of employment". In his opinion, applying a levy on robots acquired by firms would be the perfect manner to share out the extra gains deriving from labour-saving technology. Undoubtedly, this mechanism would foster a slowdown in technology R&D, but it would be beneficial for governments having time to figure out a solution for technological unemployment. To Gates, if one takes a long-run perspective, labour displacement is not such an adverse condition. He believes it would free up employees, granting them the chance to work in those sectors where there is still a shortage of help, like social services or education. To take care of elderly, children, and sufferers one need empathy and understanding which are not yet human traits replicable via machines. On the basis of such debate, several scholars investigated the economic benefits deriving from this kind of policies: the strategic patterns for their implementation, the resulting welfare gain, the likely effects for firms' productivity and the advantages on the labour market side. The question is whether it is optimal to tax robots and how to do it. In Guerreiro et al. (2020), two categories of occupations are detected: *routine* and *non-routine* ones. When technical progress makes automation costs decrease, income differential between the two classes of workers widens; the minimum wage of routine workers has necessarily to diminish to stay competitive. The authors propose a Mirrleesian type of optimal tax policy. In the modern version of the Mirrlees model, optimization is based on the *revelation principle.*

"Any optimal allocation of resources can be achieved through a policy under which individuals voluntarily reveal their types in response to the incentives provided." (Mankiw et al., 2009, p. 150)

In so doing, the policymaker makes sure the taxation system does not induce non-routine workers to choose the same *income-consumption bundle* of routine ones in order to skip heavy duties. Hence, the hardest part is supplying the right incentives so that high-ability taxpayers continue working in compliance with their maximum faculty albeit this would mean paying higher charges (Mankiw et al, 2009).

In the Guerreiro et al. (2020)'s framework the motivation lies in the skills choice. By means of the word "robots", they denote production inputs that are complements of non-routine workers and substitutes for routine ones. Therefore, their fiscal regime must incentivize young generations to enhance their high-level skills before entering the labour force as to become non-routine workers and escape robotization-driven unemployment. This is possible if the government enforces a *direct redistribution mechanism* only until current generations of routine workers are active in the labour force because they are not capable to up-skill. This period, characterized by positive robot taxes, is divided into three distinct decades. By assuming that:

- agents live for six decades, working for four of them and then retiring.
- robots can be used immediately, without considering the time spent for the building.
- robots depreciate fully within a decade.

the optimal robot tax is 5.1, 2.2 and 0.6 percent in 2018, 2028 and 2038 respectively (Guerreiro et al., 2020). By the time that the third decade expired, the labour force composition changed, and the planner should stop implementing a direct redistribution mechanism since all employees were born after the initial date: 2018. Henceforth, the optimal way for the government to improve their welfare is *redistribution through occupation choice,* otherwise there is the risk to incur in moral hazard behaviours from the part of labourers. As a matter of fact, if redistribution is still carried out via provision of subsidies or transfers, non-routine workers may opt for the same *income-consumption bundle* of routine workers. It looks attractive to their eyes as they can earn the same but working less hours. Thus, the levy on robots is transitional, after the third decade the optimal tax rate falls down to zero. So shaped, the model eventually satisfies one of the major pillars of optimal taxation doctrine: "only final goods ought to be taxed, and typically they ought to be taxed uniformly" (Mankiw et al., 2009) and robots are intermediate goods, indeed.

3.3 Policies: theories and governments interventions

It is almost assured that automation, robotization and AI technology advancements will produce a spike in GDP of countries in the long-run. However, recently economic growth looks hampered and proceeds slowly. According to economists, the causes are productivity undermeasurements and development lags similar to the ones experienced in the wake of computers introduction (Korinek and Stiglitz, 2019). As Robert Solow pointed out in 1987, these new devices were not present in productivity statistics, aggregate yields raised after the reorganization of the business. Nevertheless, scholars have faith in a boost of markets although they believe the already existent income inequality within and among states will exacerbate consequently. If technological progress is effectively capable to make everybody better-off, the point is how to tap into economic policies to promote the process. Redistribution is generally necessary to achieve Pareto improvements in the economy albeit market imperfections like high transaction costs, pecuniary externalities and information asymmetry push inward the Pareto frontier. Since in the past economic policies shaped the outcomes of innovation, the assumption is supposed to hold true for AI and comparable high-tech trends (Korinek and Stiglitz, 2021). Besides, US, EU, and other nations have already drafted or implemented a number of economic measures aiming in particular at the harmonization of rules and sensibilization of citizens on the topic. In 2019 OECD's member states adopted the *OECD Principles on Artificial Intelligence*, a list of enforcement criteria, standards of practice and recommendations for governments as to encourage "the promotion of AI that is innovative, trustworthy and respects human rights and democratic values" (OECD, 2021, p.5). The paramount spheres that should be touched by governmental policies are the following:

1) *TAXATION AND REDISTRIBUTION*

Taxation can influence the welfare gains acquired after technological progress in two ways: through the chosen type of fiscal regime and by means of the factor of production up on which the levy applies. Korinek and Stiglitz (2021) recognize the importance of progressive taxation to spread economic growth uniformly. Yet governments tend to adopt gradually more regressive tax systems, and this is not consistent with economic theories. Concerning the taxed factor, instead, a duty on rents can be useful to enhance the system efficiency, while capital taxation may harm technological progress as capitalists are less prone to invest on it. Anyway, both capital and rents are taxed at lower rates than labour. To grant a more equitable distribution of technology surplus, without incurring in previously mentioned efficiency losses, the authors propose several solutions. Firstly, reallocating the quasi-rents earned by the "winners" of technical improvement. This method is not producing distortions and can be enforced by charging a levy on "monopoly rents of digital giants" (Korinek and Stiglitz, 2021, p.26). Secondly, one can adopt a Pigouvian type of levy which applies on "bads" generating negative externalities (like pollution). It could be a way to attain two distinct goals in one shot given that this resolution could foster Green Transition at the same time. Furthermore, Korinek and Stiglitz (2021) are not "universal basic income" supporters, judging it irrational as long as it is not really "universal" but confined within national boundaries. To them, it is more reasonable to focus on the creation of new jobs opportunities, for now. On the contrary, social insurance against disruptive innovations would be helpful since it extends the individual risk to the entire community. However, unless it is a perfect insurance, redistribution is still necessary because this type of insurance would call for the payment of a large premium (Korinek and Stiglitz, 2019).

2) *EXPENDITURE AND INFRASTRUCTURE*

The second sort of actions governments can implement concerns public expenditure and infrastructure. Raising government spending, indeed, can provide a double-benefit because the demand for unskilled labour increases while income disparities are softened. This mechanism is often referred to as "pre-distribution". An example of labour-intensive expenditures are investments in infrastructures, both in the digital and transports sector. The former gives countries the chance to advance on the technological side and to shorten the digital gap. The latter works as a policy stemming wage decline. In facts, if the government sets high salaries in the public sector, the wages of private firms' employees increase to hold the comparison and the bargaining power of workers boosts (Korinek and Stiglitz, 2019).

To illustrate some practical interventions: *Aurora AI* is a project enacted by the Finnish Ministry of Finance to promote the adoption of artificial intelligence in the public administration. It consists in a “network of different smart services and applications” designed to offer “personalised, one-stop-shop and human-centric AI-driven public services” (OECD, 2021, p.18).

On the other side, when dealing with digital infrastructures, the European Union Joint Undertaking (EuroHPC) is planning the development of a “petascale and pre-exascale supercomputing and data infrastructure to support European scientific and industrial research and innovation” (OECD, 2021, p.19). From 2020 these supercomputers are expected to show up in Slovenia, Luxembourg, Czech Republic, Bulgaria, and Portugal.

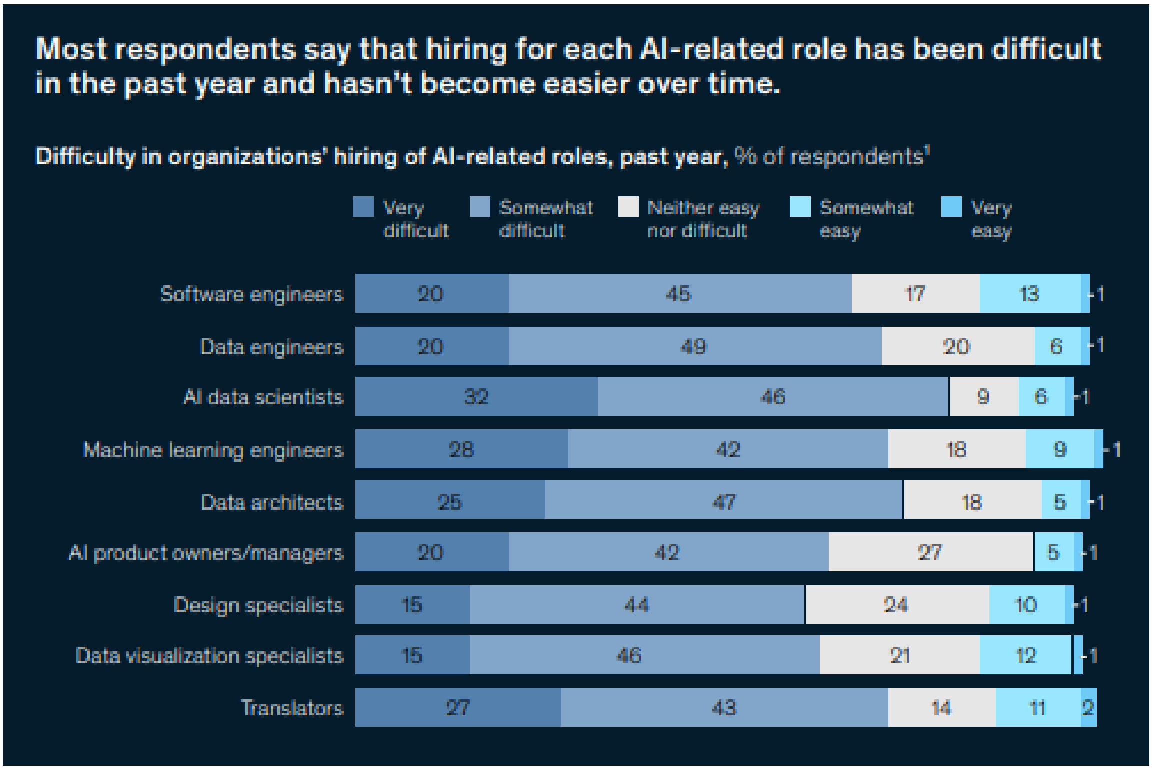
3) *INTELLECTUAL PROPERTY RIGHTS*

Always according to the analysis conducted by Korinek and Stiglitz (2019), modifying intellectual property legislation is the clearest example of institutional change that would entail advantageous market distribution. If the protection reserved to inventions through patents expires before, not only the utility derived from the innovation will be shared, but also a part of the surplus gained by innovators will be allocated to workers or customers. Disclosing publicly the invention ingredients contributes to the well-being of workers by way of lower prices, but there is a resultant unavoidable downside: the pace of innovation may tend to slowdown. In spite of that, the authors argue there exist an “optimal patent life” for which societal welfare and progress are both shielded. In their intertemporal model, the growth rate is a function of the length of patents and of the tax rate of innovators. A part of profits is invested by entrepreneurs, hence it is a function of the growth rate, while the remaining portion is kept. The relation between these elements provides us the *present discounted value* of workers’ income which is possible to maximize by selecting the optimal length of patent and the optimal tax rate. Regrettably, AI represents a challenge from this perspective. Its nature, made up of fast-changing algorithms, escapes intellectual property law (Korinek and Stiglitz, 2021).

4) *EDUCATION*

The McKinsey Global Institute took a survey to study AI advances over the past five years. The results were published in a discussion paper (2022) reviewing current technological developments. The research revealed how businesses are recently struggling in finding personnel endowed with a sufficiently high degree of IT skills. Moreover, the lack of AI-experts does not seem to lessen as time passes by but, on the contrary, it becomes harder and harder to be able to find a properly equipped and qualified workforce to fulfil the vacancies. Hence, firms are willing to invest on workshops, masters and trainings for the upskilling or reskilling of present employees as to let them acquire a suitable proficiency profile.

Table 6. Difficulty in Organizations' Hiring of AI-Related Roles.



Source: McKinsey Global Institute (2022)

One of the five recommendations provided by the OECD's framework on AI principles stresses the value of "empowering people with the skills for AI and support workers for a fair transition" (OECD,2020, p.6). Then, one can infer that governments acknowledged the value of technological investments for the education system. At the moment, the two nations displaying the major interest concerning the issue are US and Finland. The first one saved a conspicuous fund to be spent for the enhancement of high-quality computer science training. The second one adopted a broader view. To Finland, acquiring a basic knowledge in AI represents a "civic competence" which every ordinary citizen should be endowed with. To this end, the University of Helsinki released a ten-hour Massive Open Online Course to grant Finnish a minimum familiarity with the matter, including the elderly (OECD, 2021).

Ultimately, the last field touched by AI development is regulation and ethics. There are some negative outcomes potentially associated with its realization which might prejudice the safety and security of countries. For instance, privacy violations, hate incitements, societal divides and political manipulation are the ones emphasized by Korinek and Stiglitz (2021). Address them by enforcing a set of rules to is the priority of governments. Yet the focus shifts towards a different problem. Is the probability of incurring in such dangerous situations equally spread around the world or there are more or less threatened countries? And if damages arise, would they impact with the same magnitude on everybody? For Korinek and Stiglitz (2021) developing countries are to handle an unfavourable position.

3.4 A spotlight on developing countries' peculiar condition

Developing countries' technological scenario is a sensitive topic. For historical reasons, these regions have always occupied a subordinate position in the global economic context and a series of factors are preventing them from attaining the same level of development of western economies. The main causes of their slow and struggled GDP growth are political instability, social injustice, a poor institutional and legal framework, a high-level of corruption, a difficult access to basic healthcare, an inadequate educational system, and deep-rooted inequality. Inequality, in particular, is inclined to suffer from technological advances that may furtherly deepen the problem and exacerbate today's discrepancy between third world nations and developed economies. Moreover, as Korinek and Stiglitz present in their working paper (2021), there are several dynamics for which the current technological transition may have a harder impact on emerging markets.

3.4.1 Three main issues

Despite progress shifts the production possibility frontier, stimulating factors productive efficiency, the allocation of welfare gains is unknown. The previous paragraph displays a collection of methods to allow a more equitable distribution of gains, but when extending the perspective globally, the situation gets trickier. The high-income country turns out to be the winner and has to compensate the loser redistributing gains across national boundaries. The solidity of international co-operation needs to be strengthened to attain such goal. There are three different types of progress producing downside risks for developing countries (Korinek and Stiglitz, 2021).

1) *RESOURCE-SAVING TECHNOLOGICAL PROGRESS*

Thanks to AI and other recent technological transformations it is possible to exploit less environmental resources to produce the same level of output or even less, contributing in such way to efficiency increases. Although this occurrence is compliant with Green Transition and environmental economics principles, it is ultimately harming developing countries' economies since their comparative advantage is tightly linked to natural resources utilization.

"A natural resource-saving innovation reduces the terms-of trade and the total income of the resource-exporting developing country, making it worse off in absolute terms" (Korinek and Stiglitz, 2021, p.9).

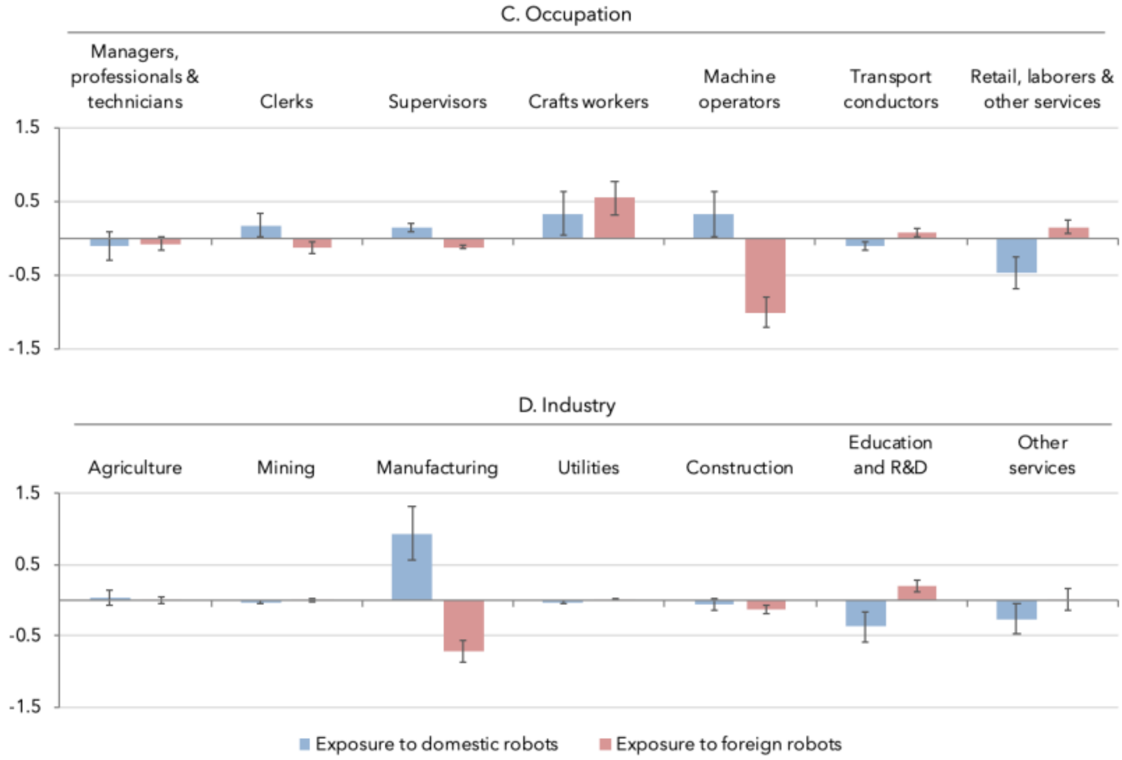
2) *LABOUR-SAVING TECHNOLOGICAL PROGRESS*

In chapter two the investigation focuses on the negative impact of automation technology on the labour market demand and supply. There may be harmful consequences for both low and high skilled labour force, but in the case of developing countries the problem intensifies. As these countries rely very much on cheap unskilled labour, a decline in the demand for this factor would deteriorate their total income and terms-of-trade (Korinek and Stiglitz, 2021). In addition to this, robotization fosters *reshoring* which is the opposite trend than *off-shoring*: the decentralization of factories activities to exploit the factors abundancy of other places. In the past, cheap labour abundancy of low-income countries like Mexico persuaded large firms to transfer there the manufacturing steps of their value chains. Nevertheless, automation cuts the costs of production letting enterprises re-centralize as to incur in lower import-export expenses. Faber (2021) tried to predict foreign robots exposure comparing Mexican local labour market data and the degree of robotization in the US labour market between

1990 and 2015. His findings proved an inferior growth of the employment-to-population ratio by 0.43 percentage points which means 270,000 fewer jobs!

Table 7 exhibits the impact of robots exposure according to occupations and industries. Machine operators shall experience a decrease in the amount of open positions by 400,000 units, while in the manufacturing sector 330,000 fewer workers are expected to be needed due to foreign robots. (Faber, 2021)

Table 7. Impact of Exposure to Robots on Occupation and Industry.



Source: Faber (2021)

3) *DIGITAL MONOPOLIES AND "SUPERSTAR FIRMS"*

The last dynamic extrapolated by the scholars that would undermine the development of poor countries is the accumulation of market power by the part of dominant firms. This mechanism is a little bit redundant as it takes place similarly in western countries domestic economies. Given the inner structure of artificial intelligence (an information good characterized by very low marginal costs), the natural shape of its market is a monopoly. Considering that developing economies are in shortage of capital for R&D investments and lack an appropriate intellectual property legal framework, the acquisition of a dominant position by western countries is almost assured. The domestic notion of “superstar firms” would be extended to the one of “superstar countries”. Therefore, it is even harder for developing countries to catch up the lagging technological and economic progress.

3.4.2 Proposed solutions

In Korinek and Stiglitz (2021), high-income regions monetary or economic policies are at the basis of developing countries problems. Their tax policies and interest rates shape automation so that it becomes labour-saving and excessive (Acemoglu, 2020). The responses suggested differ depending on whether they need to be implemented within the national boundaries of countries (by their governments) or at global level. The first type of policies, for example, account “steering the adoption of technologies”, which means “orienting technological development”, towards labour-using rather than labour-saving devices. Concerning intellectual property rights, instead, developing countries would be significantly helped if they were empowered via license to use the technology of western innovators before the patent expiration date (Korinek and Stiglitz, 2021).

At global level, international competition policies are at the stake. The problem is that developed countries are reluctant to fine domestic tech giants as they contribute very much to enhancing the GDP of the nation. To fix the issue, in September 2019 the Council of Europe appointed a committee tasked to “examine the feasibility of developing a legal framework for the development, design and application of AI, based on CoE standards on human rights, democracy and rule of law” (OECD, 2021, p.23). Furthermore, the OECD is discussing the proposal of a global tax regime able to transcend national borders in the spread of innovation surpluses.

Conclusion

Once reviewed the past and present technological evolution and after having theorized its potential future unfolding, we might try to answer the questions motivating the redaction of this paper.

In the initial chapter, past technological revolutions, which influenced if not overturned the historical path, have been analysed. The purpose was finding analogies and differences with respect to what we are experiencing in terms of technological transition nowadays. We have observed a recurring theme of development throughout history. Each time, a new invention enters the historical course of actions aggressively, disseminating panic among citizens and the working class in particular. Nevertheless, the economic system has always proved to be resilient. Breakthroughs, of various genres, generate a period of recession, where unemployment raises and aggregate demand decreases, but after a while economy rearranges. Automation, robotization and artificial intelligence may in turn initiate a problematic period of transition, yet providing substantial wealth in the end of the cycle by means of welfare increases and economic growth. Maybe this time it will be even more demanding than in the past or the consequences will be the most disruptive ever experienced, but as long as policymakers intervene wisely to flatten social divides, fulfil legislative gaps, and improve the schooling apparatus, a solution can be found. In this regard, I personally support the lesson of Adam Smith, which remains up to date albeit dating back to the origins of economic science.

"Little else is requisite to carry a state to the highest degree of opulence from the lowest barbarism but peace, easy taxes, and a tolerable administration of justice." (Smith, 1755)

Adam Smith believed the key for the development and prosperity of a country was possessing adequate institutions. With regard to technological upgrading, they represent the channel throughout which benefits are enhanced and negative outcomes narrowed. A good education system also makes the difference by teaching citizens and future generations how to deploy technology properly and ethically in their daily life or working activity (see the Finland Case, Chapter III, paragraph 3). After all, recalling the doctrine of “creative destruction” (Schumpeter, 1942) mentioned in the early pages of my thesis, it is a never-ending process of creation, destruction of the old and re-creation from its ashes. Nothing ends. Technology and progress simply model the shape of societies and we need to be forward-looking and open to changes.

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