UNIVERSITA' DEGLI STUDI DI PADOVA

DIPARTIMENTO DI SCIENZE ECONOMICHE ED AZIENDALI
"M. FANNO"

CORSO DI LAUREA MAGISTRALE IN
BUSINESS ADMINISTRATION

TESI DI LAUREA

Industry 4.0 at work:
economic implications and evidence from the Italian market

RELATORE:

CH.MO PROF. ANDREA FURLAN

LAUREANDO: MATTEO PELLEGRINI

MATRICOLA N. 2005811

ANNO ACCADEMICO 2021 – 2022

Dichiaro di aver preso visione del "Regolamento antiplagio" approvato dal Consiglio del Dipartimento di Scienze Economiche e Aziendali e, consapevole delle conseguenze derivanti da dichiarazioni mendaci, dichiaro che il presente lavoro non è già stato sottoposto, in tutto o in parte, per il conseguimento di un titolo accademico in altre Università italiane o straniere. Dichiaro inoltre che tutte le fonti utilizzate per la realizzazione del presente lavoro, inclusi i materiali digitali, sono state correttamente citate nel corpo del testo e nella sezione 'Riferimenti bibliografici'.

I hereby declare that I have read and understood the "Anti-plagiarism rules and regulations" approved by the Council of the Department of Economics and Management and I am aware of the consequences of making false statements. I declare that this piece of work has not been previously submitted – either fully or partially – for fulfilling the requirements of an academic degree, whether in Italy or abroad. Furthermore, I declare that the references used for this work – including the digital materials – have been appropriately cited and acknowledged in the text and in the section 'References'.

Firma (signature) ……Matteo Pellegrini……

INDEX

INTRODUCTION

In a constantly evolving world, where people are increasingly interconnected and companies base their success on innovation, technological advances represent a crucial milestone. However, differently from the previous Industrial Revolutions, this time we are facing a more than ever potential disruptive phenomenon, able to force a change in a way we are still not aware of. Connectivity, computing power and automation will reach an extreme level, dramatically impacting people’s lives and industry operations. In this context, as already happened in the past, technological developments are being seen in a twofold way: great opportunities on the one hand, great threats on the other. Indeed, although the main purpose of innovations is to improve productivity and realize economic gains, under certain conditions they can cause a reduction in employment and wages. The objective of the present work is specifically to understand, at least at a preliminary level, the impact of the new Industry 4.0 paradigm on the main labour market variables, adopting first a macro perspective and focusing then on the Italian market.

As a starting point, it will be presented a roadmap across the different Industrial Revolutions, followed by a brief description of what is to be intended as Industry 4.0 enabling technologies. As additional basis for the present work, previous findings concerning the relationship between technological developments and the main labour market variables (productivity, employment, and wages) will be equally provided. However, as we are only at the beginning of this new Industry 4.0 paradigm, the main results will concern primordial automation, represented by industrial robots and basic artificial intelligence. Acemoglu and Restrepo theoretical model will be the main source for the analysis and interpretation of such results.

Subsequently, given the relatively stable level exhibited by the labour share of income over the last century, the first research question will be addressed, namely whether this variable is turning towards a consistently downward trend in recent decades. Moreover, it will also be investigated whether, among the various possibilities, technological development can be regarded as the main cause of this phenomenon. Empirical studies will focus on specific OECD countries, which have been selected for their relevance in the international landscape and to have a geographically diversified panel.

After performing this analysis, the focus will shift from automation in general to the primary topic of the present work, namely Industry 4.0. The initial idea was to compare the above-mentioned OECD countries in terms of new technologies implementation, investigating the possible factors that may have favoured a country’s higher adoption level. Due to data availability, however, it was only possible to study the European panorama, for which not only policies, but also driving forces and barriers will be examined. Having fully articulated the main variables under study and provided important insights, in the last chapter the second research question will be taken into consideration, namely whether and eventually how strongly Industry 4.0 has impacted the Italian economic system.

In this scenario, moving from a macro to a micro perspective, and from a qualitative to a quantitative analysis, evidence will be provided on both the level of new technologies adoption and the traits of the most innovative Italian companies. Finally, the last part of the chapter will be devoted to estimating the impact of the Fourth Industrial Revolution on productivity, employment and wages, the variables which have represented the common thread for the entire work. The main source for these data will be the Bank of Italy's "Survey of Industrial and Service Firms".

1. A ROADMAP TOWARDS INDUSTRY 4.0

1.1. From the First to the Third Industrial Revolution

When we speak about industry innovation, it is paramount to refer to the biggest industrial revolutions we have experienced in the last four centuries. The notion of "industrial revolution" has historically been associated with a rapid major change "*from an agrarian and handicraft economy to one dominated by industry and machine manufacturing*[1]", but the origin of the term is quite disputed. In fact, although there is evidence of its use at the beginning of the 18th century by some German and French authors (Bezanson, 1922), the English historian Arnold Toynbee has been considered the father of the term, as he was the first one to popularize it. Moreover, it is due mentioning that the collection of his unfinished lectures, published posthumously in 1884 as "The Industrial Revolution", could be considered as the natural prosecution of the work started by Engels in 1845 (D. C. S. Wilson, 2014).

As Toynbee pointed out, the First Industrial Revolution, which started in Great Britain in the late 18th century, dramatically changed the status quo. At the time, most people were used to living in small rural communities and seeing agriculture as the main source of income for their survival. Food and clothes were produced by themselves and there was very little dependence on manufacturing, which was carried out mainly at home and with basic tools. In this scenario, the introduction of large-scale technological innovations gave rise to primordial industrial sectors, such as iron, coal, and textile, while the development of the steam engine allowed to overcome the limits associated with the distance between factories and deposits of raw materials. Specialization and mechanization involved both machines and workers: factories combined fixed and working capital to produce large quantities of products for domestic and foreign markets. As a natural consequence, there was a gradual contraction of agriculture and a progressive shift of investments and workforce toward industrial production.

Two phenomena must be mentioned in explaining this revolution in the UK: on the one hand, industrialization evolved as a challenge and response process to remove bottlenecks, and on the other hand, industrial advances were interrelated. These two aspects made Great Britain mine 70% of the world's coal and produce 50% of its cotton and iron by 1860 (Amatori & Colli, 2013). Industrialization then evolved in other nations, such as Belgium, Switzerland, France, Germany, and the United States, but mostly as an irregular process that took many years to

[1] Britannica, T. Editors of Encyclopedia (2022). Industrial Revolution. Encyclopedia Britannica.

complete. Finally, it is important to underline that the changes in the production process led to changes at a social level: workers had to quickly adjust their habits to the rhythms imposed by the new technologies, and oftentimes urbanization was seen dramatically. In fact, factory workers were usually forced to commute long distances or live in crowded dormitories, while machines dictated their schedules requiring high levels of performance. Moreover, it was demonstrated that "*a region's historical industries leave a lasting imprint on the local psychology, which remains even when those industries are no longer dominant or have almost completely disappeared*" (Obschonka, 2018). Researchers found out that people living in former industrial regions in the UK and the US reported more unhappy personality traits, lower life satisfaction, and lower life expectancy compared to similar regions not affected by industrialization.

The second half of the 19th century was marked by significant growth in communication and transportation networks. Specifically, the introduction of the telegraph and the telephone allowed a faster, more efficient, and extensive information exchange. The low costs and the little time they required to be installed led to a quick diffusion: in the US, for instance, the number of telegraph lines grew by about four times between 1860 and 1880. On the other hand, the development of railroads changed things decisively, enabling products to be quickly and easily sent from one place to the other. At the same time, coal and steam had a great impact on water transportation, not only improving speed and reliability but also allowing higher capacity. All these changes made firms expand their markets, improve relationships with clients and suppliers, and restructure their internal organization.

The area where these new networks made their biggest impact was in manufacturing, which was also heavily affected by many technical improvements. The complex interaction of all these innovations marked the period known as the Second Industrial Revolution, which distinguished itself from the previous one because of the increased volumes and the faster rate of change. This phase was characterized by many positive outcomes, such as a higher speed of shipment of goods and the rise of large manufacturing plants able to supply mass products. In this scenario, the competitive advantage was based on the pursuit of economies of scale (due to the reduction of overall costs) and the associated economies of scale (due to single operating units capable of producing several different products).

Notwithstanding the high potential, the impact of process innovations such as automatic packaging, distillation, and electricity usage differed between industries, creating a distinction between those areas characterized by large corporations and the other sectors. Among the former, it is worth mentioning food, chemicals, oil, metallurgy, machinery, and transportation vehicles. In contrast, the latter were industries mainly based on a higher level of manpower, such as clothing, textiles, furniture, and printing, where the mechanization process was simpler, and machinery was used to help rather than to substitute workers.

Two business areas were subject to substantial changes during this period: production and distribution. Regarding the former, it is essential to mention the impact in terms of labour organization due to the emergence of Taylor's "scientific organization": the work was divided into functional essential tasks, salaries became higher, but foremen, workers, and unions had no more interference in plant operations. As is well known, this philosophy represented the basis for the Ford Model T assembly line. Finally, in terms of distribution, it was clear that the increased amount of goods produced could not be sold through traditional means. Furthermore, after firms started differentiating their products, specific technical and sales skills were needed. The answer to this challenge was represented by vertical integration, which gave manufacturers both the opportunity to directly serve the needs of the customers and to gain information on their preferences.

Differently from the above-mentioned innovations, the advances of the Third Industrial Revolution were driven by the intense demand on manufacturing industries imposed by World War II. In fact, during the 20th century, new developments were made in many areas of applied military research, including chemicals, pharmaceuticals, air transport, electronics, and new materials (synthetic fibres and plastics). This revolution, despite being trailed by the US and Germany, occurred also in other countries, where similar innovations emerged. However, as a general pattern, this period was marked by the creation of totally new industries, with radical changes in at least three main business areas. The first was communication, where the diffusion of both the Internet and modern systems (such as personal computers and telephones) allowed massive telecommunication networks. The second area concerned transportation, with the construction of bigger and faster aircraft, powered by jet engines and running on special fuels: civil aviation could benefit from the reduction of costs and an era of mass air transport was launched. The last cluster was physical materials, with the conversion of the knowledge in applied physics from the creation of the atomic bomb to the production of nuclear energy, which was extremely important to counterbalance shortages and price increases in traditional sources.

As during the previous revolutionary periods, a crucial factor was represented by the availability of general-purpose technologies (GTP), meaning technologies that could be applied to a wide range of industries. In fact, the role played by steam power in the First Industrial Revolution and that of electricity during the Second Industrial Revolution was taken by the semiconductor (and its successor, the integrated circuit) during this third revolutionary wave. Although this innovation immediately captured the interest of the defence industry, in less than ten years private consumption surpassed public procurement, given the importance of these components especially in the development of personal computers and in the field of automation.

By the mid-20th century, it was clear that all the new advances were generating important economic opportunities, both in the leading nations and then around the world: reduction of physical distances, free movement of people, goods, and resources, increased information exchange, and higher intensity of world trade.

1.2. The Fourth Industrial Revolution and its building blocks

At the beginning of the 21st century, it was clear that a new revolutionary period was being built on the previous one. Huge advances on the technological side and profound impacts on the societal level were only two of the factors signalling the opening of a new era. However, the term "Forth Industrial Revolution", also known as Industry 4.0, did not occur before 2011, when the German government started talking about its high-tech strategy aimed at the promotion of digitalization in manufacturing. Indeed, in 2013 some local associations established the "Plattform Industrie 4.0", intending to coordinate the implementation of the aforementioned project at the business level. At the time, the plan was seen as a combination of unprecedented flexibility and resource utilization, offering Germany the opportunity to strengthen its position not only as a manufacturing location, but also as an equipment and IT supplier[2].

Notwithstanding the first initiative came from Germany, similar projects have been developed all over the world, the most important being the "Industrial Internet" in the United States, the "Industrie du Futur" in France, and the "Made in China 2025" in China. Despite the different names, the underlying vision was the same: "*use digitization to design, build and develop an empowered virtual world that would steer the physical world*" (Nayyar & Kumar, 2019). The possibility of establishing a vision represented a point of discontinuity with the previous periods: the Fourth Industrial Revolution is predicted a priori, not observed ex-post. This peculiar aspect has resulted in some people refusing to call this process a revolution and instead associate it with an evolution of existing technologies, a hype rather than a reality[3]. However, (Klingenberg et al., 2022) after having analysed Industry 4.0 through the lens of technological

[2] Britannica, T. Editors of Encyclopedia (2022). Industrial Revolution. Encyclopedia Britannica.
of the Industrie 4.0 Working Group (2013). Towards the fourth industrial age.
[3] Drath & Horch (2014). Industrie 4.0: Hit or hype? [industry forum]. IEEE industrial electronics magazine, 8(2), 56-58

complementarities, economic institutions, and social structure, concluded: *"Although Industry 4.0 technologies are more evolutive than disruptive, the context in which they develop promises significant impacts on the economy and society, characterising a new industrial revolution."*

Given the fact that the term "Industry 4.0" is often used inappropriately, it is useful to proceed with a brief literature review of the phenomenon being considered. The starting point is represented by the key design principles of Industry 4.0, which (Hermann et al., 2015) determined to be interoperability, virtualization, decentralization, real-time capability, service orientation, and modularity.

Interoperability refers to the ability of machines, objects, and people to communicate with each other, exchanging data, and coordinating activities. This capability directly results in increased efficiency and improved processes, but at the same time requires connectivity and digitization of business operations. Virtualization is defined as the possibility of building a virtual copy of the physical world, making it possible to analyse and optimize machine performance, test solutions for different scenarios, and prevent potential problems related to production inefficiencies and maintenance costs. Decentralization is related to the increasing complexity of the business environment, which makes centralized management of operations increasingly difficult. Therefore, in a growing number of industries, the number of players involved in decision-making is increasing, reserving only specific decisions for the higher level. Real-time capability is associated with real-time data collection and analysis, which provide an instantaneous overview of business processes. This, in turn, enables immediate decisions to be made in the event of inefficiencies or failures on the production lines. Service orientation has the principle just presented as a prerequisite since it can be defined as the ability of companies to adapt to and serve all new customer needs and preferences using big data and the free flow of information. Consequently, the final objective is to provide a personalized customer experience, thus shifting the focus from mass production to customized products. Finally, modularity is classified as the ability of systems to flexibly adapt to changing requirements and needs. This configuration allows companies to change their processes depending on the external conditions they face, such as seasonality or new product specificities.

Having clear in mind the aforementioned principles, it is now essential to have a brief digression on Cyber-Physical Systems (CPS), since they are considered the core Industry 4.0 technology. The term was coined in 2006 by Helen Gill at the National Science Foundation in the United States and referred to "*a new generation of systems with integrated computational and physical capabilities that can interact with humans through many new modalities*". According to (Lee et al., 2015), a CPS is composed of two main elements: on the one hand, an "*advanced* *connectivity that ensures real-time data acquisition from the physical world and information feedback from the cyber space*", on the other hand, "*intelligent data management, analytics and computational capability that constructs the cyber space*". However, given the rather abstract nature of the requirements just provided, it was necessary to define a more specific model for implementing CPS at the manufacturing level. The so-called "5C architecture" was therefore developed to have a clear understanding of how to build a CPS from initial data acquisition to final value creation.

The first level, called smart connection, is aimed at acquiring accurate and consistent data either directly (mainly through sensors) or by relying on the enterprise production system, such as ERP. At this stage, it is important to consider very different kinds of data and then select the type and specifications of the sensors needed. The collected data must be analysed to obtain relevant information, a central activity of the next stage, the so-called data-to-information conversion. At this level, using specific tools and methodologies, it is also possible to give self-awareness to machines. Cyber represents the central phase of the process, as it acts as an information hub. Indeed, information flows from each connected machine to the central network, where it is further processed and analysed to obtain a clear overview of the current fleet situation. In addition, comparison with the performance of other machines makes it possible to determine where the biggest gaps lie, while the availability of historical information provides some general indications of the machine's estimated useful life and future behaviour. The following level is cognition, where infographics are used to effectively transfer knowledge to the final users: the final objective is to prioritize and optimize decisions. Configuration is the last stage, as it relies on feedback from cyberspace to physical space and acts as a control and supervision system.

1.3. The nine pillars of Industry 4.0

After a clear presentation of the building blocks of Industry 4.0, namely design principles and CPS, it is now the time to further investigate the main technological advances that were brought about by this profound digital transformation. In their report, (Rüßmann et al., 2015) referred to them as "*the nine pillars of technological advancement [that] will transform production*", as they will foster the shift from "*isolated, optimized cells to fully integrated data and product flows across borders*". In addition to the simple qualitative explanation, a practical application case will also be provided for each technology for better expository effectiveness.

1.3.1. Big Data and Analytics

Big data and analytics have been defined as one of the most crucial elements supporting Industry 4.0, as they provide highly relevant information for managing the smart factory. In particular, the data generated inside industries by machines, sensors, mobiles, or cameras is called Industrial Big Data. As soon as these devices generate data, a tracker detects it and can either send it to the cloud for higher-level analysis or store it in a database for future use. The main impacts of this technology include optimizing product quality, forecasting sales volumes, increasing throughput and supply chain efficiency, reducing costs and time, and improving customer services.

One of the most effective cases of using big data and analytics came from Kia Motors, which invested in SAS solutions to boost its performance and improve its products and services. The first change has been a better maintenance experience: before SAS, whenever a Kia dealership identified a new problem or needed support to fix one, an automated call was made to the internal Technical Assistance. After a few days, combining phone records, surveys and production data, a report was generated. Using SAS Visual Analytics, the production of this report was automated and service agents were able to provide a better experience for technicians and customers. The other key area of improvement has been product quality, with a focus on reducing warranty costs by predicting part failures. In this case, the tool used has been Weibull Analysis, a technique that established the failure rates of each component and projected them into the future using a regression line. This allowed Kia to minimize maintenance costs by quickly intervening on cars with less expensive repairs and design changes.

1.3.2. Autonomous Robots

Companies have long used robots to perform dedicated tasks in the manufacturing process, as they can provide safety, flexibility, and reliability. However, with the recent technological changes, traditional industrial robots have transformed into a new type of collaborative robots, equipped with the ability to understand the external environment, learn, and act on new knowledge. As a result, companies have seen the opportunity to use them to meet the market demand for low-priced customized products. In fact, these robots will be cheaper than existing ones, will increase productivity and at the same time will work side by side with the workers, thus reducing the overall costs.

A good example here comes from the food industry, specifically from a Swiss company (Bischofszell Nahrungsmittel AG, BINA) that has been in the business for more than a hundred years. Since the company has to ship all its products to different supermarkets around the country, a different barcode label is used to identify each order leaving the plant. However, given the need for the process of applying these labels to be at the same time quick and extremely precise, it could not be performed reliably by a human being. The solution came from ABB, a system partner that had launched YuMi, a collaborative robot for the labelling process. This cobot was capable of processing 1,200 containers every hour in a two-shift operation from Monday to Friday without needing any breaks. Furthermore, not only did it work without the need to protect grids or other safety devices, but it could also be programmed for other tasks when needed.

1.3.3. Simulation

In the world of engineering and logistics, modelling and simulation are already being used to test and validate products, materials, and production processes, while supporting decision making. Simulation is defined as "the process of designing a model of a real or hypothetical system to describe and analyse the behaviour of the system" (de Paula Ferreira et al., 2020): it often involves the creation of a digital twin based on real-time data, a virtual copy of the physical world. Among the main implications, it is due mentioning the possibility of conducting tests without interrupting the current system, optimizing the production process by choosing among different configurations, but also identifying the best machine settings for a new product line, thus reducing setup time and improving quality.

An interesting case is that of Admiralty Shipyards JSC, one of the oldest and largest shipyards in the Baltic region that produces mainly submarines for the government, but also non-military underwater constructions for commercial clients around the world. Given the huge order it received for diesel-powered submarines, the company had to assess whether it could meet the order with its existing facility or whether it needed to expand its operations. Using AnyLogic simulation software, JSC modelled the entire plant production process, at the same time simulating the connections between different departments, the characteristics of the orders received, and the requirements in terms of quantity, labour commitment, and timing. The results confirmed that JSC was able to accept the large order without the need to build additional plants and with a workload percentage of 80% or less. Finally, the model offered the company greater insight and visibility into the production, distribution, and connection processes between units.

1.3.4. Horizontal and Vertical System Integration

In addition to ensuring the interconnection between machines, materials, and products, to take companies to the next level, Industry 4.0 must foster effective communication between all these factors. In this regard, it is important to distinguish between horizontal and vertical system integration. The first is defined as communication provided to each stakeholder involved in the supply chain of a specific product so that each part is updated with the latest information added in a cloud. The second refers to communication within an organization, with the intent of increasing transparency, merging the different stages of production, and enabling internal data collection.

The way Airbus changed the final scope of its new aviation data platform provides a case in point. Indeed, the original Skywise platform, launched by the French giant, had been developed as a reference point for major aviation customers, offering enriched data to analyse their business performance and support their digital transformation. In fact, the platform did not just provide operational data, but was enriched with additional information, such as internal reports and technical documents, as well as the cumulative knowledge of engineers. After some time, Airbus decided to provide suppliers with access to Skywise as well, thus bringing productivity gains to stakeholders in the entire aviation industry. This decision has proven to be very positive, as it has yielded excellent results in terms of on-time delivery, quality, and reliability.

1.3.5. Industrial Internet of Things

Among the main Industry 4.0 enablers, the Industrial Internet of Things (IIoT) has certainly played an essential role. After an extensive literature review, (Boyes et al., 2018) classified it as "*a system comprising networked smart objects, cyber-physical assets, associated generic information technologies and optional cloud [...] which enable real-time, intelligent, and autonomous access, collection, analysis, communications, [...] so as to optimize overall production value*". Through IIoT, more and more devices have been enriched with embedded technology and connected to each other, thus decentralizing decision-making and reducing the complexity of communication between machines. This, in turn, has improved product delivery, increased productivity, and reduced labour and energy costs.

A quite famous example is represented by the Caterpillar Marine Division, which serves targets operators for whom fuel consumption is often critical. Since shipboard sensors monitored everything, from generators to engines, to fuel meters, Caterpillar was able to reconfigure every process so that it complies with the optimum operating parameters. Specifically, through multivariate analysis, the company discovered how running more generators at lower power was more efficient than running less but with maximum power. The savings achieved have been estimated at about $30 per hour, which may not sound like much, but the combined savings for a fleet of 50 ships operating 24 hours a day and 26 weeks a year would generate savings of more than $650.000[4].

1.3.6. Cybersecurity

Increased connectivity between different cyber-physical systems has not only increased efficiency but also the threats of cyber-attacks. Therefore, cybersecurity is considered a primary concern for any company adopting Industry 4.0 technologies, as it represents a guarantee to protect sensitive data and information against any unapproved access or abuse.

One of the most famous cases was Flame, a PC malware that attacked Microsoft Windows in the Middle East Area, spying and collecting private data through Local Area Networks (LANs). Flame's main target was the thousands of Iranian Oil Ministry computers, from which it recorded conversations, obtained telephone numbers from nearby Bluetooth devices, stored files, screenshots, and other contents, but also scanned local Internet traffic obtaining usernames and passwords. At the time, as stated by (Munro, 2012), it was evident that "*Traditional anti-virus software is sadly ineffective against such sophisticated attacks. Organizations need to move to a whitelisting model if they want to stand any chance of beating off the attacks of the future*". Following this path, in recent years there has been an increasing trend of industrial equipment vendors entering into acquisitions and partnerships with cybersecurity companies.

1.3.7. Cloud Computing

For many years, manufacturers have been collecting data to improve their operational performance. However, the size of data generated and analysed has steadily increased, such that the existing infrastructures can no longer handle this huge amount of information. In addition, the growing need to access these data anytime and anywhere has increased the requirements. Cloud computing is one way to address all these needs, as it allows data to be stored and accessed remotely, without the need for a dedicated infrastructure: this, in turn, means that there

[4] Bernard, Marr (2017). IoT And Big Data At Caterpillar: How Predictive Maintenance Saves Millions Of Dollars. Forbes.

is an opportunity for scalability. Finally, if implemented correctly, the cloud can improve operational efficiency and flexibility, as well as reduce redundant data and operational costs.

A relatively recent example can be seen in the 2018 strategic partnership between Volkswagen and Microsoft to develop one of the largest automotive clouds. Conceived as part of the larger project to build an end-to-end software platform, Volkswagen Automotive Cloud is expected to manage data from millions of connected vehicles around the world, completely transforming the driving experience. In fact, in addition to enhancing existing services like emergency assistance and remote control, it will also lay the foundation for new areas such as intelligent navigation, smart parking, and automated driving.

1.3.8. Additive Manufacturing

As mentioned above, the manufacturing process is shifting from mass production to custom manufacturing, thus requiring new techniques. Additive manufacturing, also known as 3D printing, is a layered method of making products with specific designs and materials: it uses computer-aided design (CAD) software or 3D object scanners to deposit material, layer upon layer, into precise geometric shapes. Within the Industry 4.0 landscape, it represents a crucial application, as it enables faster production of components and prototypes, both by decreasing the complexity of the system and by decentralizing the production process: printing stations eliminate the need for intermediate products and drastically reduce storage and warehousing procedures.

Adidas Futurecraft has been one of the most effective ways to adopt custom manufacturing in the footwear industry. The project consisted of a 3D-printed running shoe that combined software and robotics to exactly reproduce the contours of an individual runner's foot. In this way, the German giant was able not only to meet the individual needs of consumers, but also to shorten the product cycle time and reduce the risk of excess inventory. Finally, this innovative production method generated almost no waste and allowed the shoes to be produced locally, minimizing shipping costs.

1.3.9. Augmented Reality

The last key technology that characterizes Industry 4.0 is augmented reality (AR), which can be described as an interactive, virtual experience of real-world environments or objects. It offers people the opportunity to experience an augmented world by superimposing virtual information over reality. In contrast with Virtual Reality, AR does not create fictitious conditions but superimposes perceptual elements on real objects: text, images, audio, video, and animation are added to improve the perception of the object and provide an enhanced user experience. Finally, it has been recognized that Augmented Reality enhances the entire manufacturing process, improving throughput and reducing costs. Indeed, it provides clear and real-time visual instructions to operators, thus improving its performance and overall safety.

A very recent development of such technology was implemented by Porsche as a result of constraints due to the global pandemic. In fact, due to the inability of Field Technical Experts to personally visit dealerships, the company decided to implement a pioneering initiative called Tech Live Look. It consists of smart glasses that allow technicians to connect directly with experts hundreds of miles away. On the one hand, these experts could project schematic drawings on the technician's glasses display, as well as take screenshots and enlarge images for better visibility. On the other hand, the technician could open and view documents while working on the car. Since this initiative has been shown to reduce intervention resolution time by up to 40%, it has begun to be used regularly.

2. HUMAN LABOUR AND TECHNOLOGY: A LITERATURE REVIEW

Having described the path towards the Fourth Industrial Revolution and explicated its key foundations and applications, it is now important to define the theoretical concepts on which to base the following elaborations. Specifically, the Acemoglu and Restrepo model, which is the basis of many academic works, will be presented. A historical overview of the main research findings in terms of the economic effects of new technologies will then be provided. In particular, the analysis will focus on three of the most important building blocks of an economic system: productivity, employment, and wages. However, since most of the research carried out generally refers to robots and artificial intelligence as proxies for technological advances, it has been deemed appropriate to provide a quick description of these two components, which had not yet been covered in this work.

2.1. Industrial Robots and Artificial Intelligence

The thought of an industrial robot, or an automated machine able to perform human tasks, has existed long before its effective implementation. In fact, although its origins can be found in Greek literature, it was not until 1954 that George Devol filed the first patent for an industrial robot capable of transferring objects from one point to another. This idea turned into a company called Unimation, which in 1961 began supplying General Motors, one of the largest manufacturers at the time. After a period of weak demand, in the mid-1970s the industrial robot industry steadily increased in size and improved the underlying technology through new developments. Nowadays, the universally accepted definition of industrial robots is the one proposed by the International Organization for Standardization (ISO) in 2012: "an automatically controlled, reprogrammable, multipurpose manipulator, programmable in three or more axes, which can be either fixed in place or mobile for use in industrial automation applications" (ISO 8373).

On the other hand, the first use of the term Artificial Intelligence (AI) dates back to the summer of 1956, when a research project on the topic was conducted at Dartmouth College. A plaque placed there in 2006 to celebrate the 50th anniversary of the workshop also states its origin: "*every aspect of learning or any other feature of intelligence can in principle be so precisely described that a machine can be made to simulate it*". Following this logic, it was subsequently declared that "*human minds and modern digital computers were 'species of the same genus' […]; both take symbolic information as input, manipulate it according to a set of formal rules, and in so doing can solve problems, formulate judgments, and make decisions*" (Dick, 2019). However, whereas in the past the main goal was to learn from human intelligence and resemble it as closely as possible, today the focus has shifted toward designing automated systems that can perform better than humans in every situation they face. This shift, although not yet achieved, was made possible by replacing the idea that human intelligence was the sole result of what people think, assuming instead that it also depended on what people know. As a result, a subsection of AI was born, namely machine learning: computer programs, using complex algorithms, could automatically learn insights and adapt to specific situations without requiring human intervention[5].

As mentioned earlier, in the Industry 4.0 landscape, while the original industrial robots have been replaced by more collaborative and autonomous entities, artificial intelligence has remained in play. Indeed, its massive use by machines to perform complex tasks, reduce costs, and increase the quality of products and services is at the heart of the Fourth Industrial Revolution. Furthermore, the use of AI makes manufacturing processes smarter, resulting in greater customization and faster time-to-market (Ribeiro et al., 2021). Therefore, as noted in (Gómez et al., 2016), artificial intelligence will play an enabling role in the transition to the so-called "smart factory", a place where humans, machines and other resources will collaborate and communicate with each other. This will be possible through the development of complex networks that will provide machines with the ability to learn, reason, and act, thus reducing overall effort.

2.2. Automation versus augmentation

A crucial factor that determines the net effect of artificial intelligence on an economic system is considered its final application, namely automation or augmentation. While the former relates to machines replacing human activity, the latter refers to the direct collaboration between these two entities to perform a specific task. The general advice that the literature has consistently promoted is that managers should prioritize augmentation over automation. Nevertheless, adopting a paradoxical perspective, (Raisch & Krakowski, 2021) argued that the two

[5]As clarified in Mitchell (1997), "A computer program is said to learn from experience E with respect to some class of tasks T and performance measure P, if its performance at tasks in T, as measured by P, improves with experience E".

applications cannot be explicitly separated since they are contradictory and interdependent at the same time. In fact, on the one hand, automation and augmentation are in contrast because companies can either choose one or the other approach to perform a specific task; this tension is further reinforced by the fact that different actors operating in an organization have different preferences[6]. However, on the other hand, by increasing the temporal and spatial scale of the analysis, it is possible to understand how the two applications are not only contradictory but also interdependent.

First, the nature of the task determines which approach will be chosen by an organization: it is evident that automation is more suitable for relatively routine and structured activities, while augmentation better adapts to complex and ambiguous tasks. In this scenario, by shifting the temporal scale from one point in time to its evolution over time, it is possible to recognize a cyclical relationship between the two applications. Indeed, augmentation is a co-evolutionary and iterative process during which humans and machines exchange knowledge and learn from each other. Eventually, this close collaboration can result in the identification of rules and methods that work extremely well in specific situations, either achieving the optimal outcome or getting very close to it. If these models are sufficiently robust, they can be implemented to automate an activity and let people focus on other more demanding and valuable tasks. Obviously, as external conditions change, organizations will need to go back to augmentation to understand whether the model can be adjusted.

Furthermore, given the evidence of interdependencies between the various activities that constitute a process, it is interesting to examine the consequences of elevating the spatial scale from one to multiple tasks. Whenever an organization automates a task previously performed by humans, this change affects all the other closely related human activities, which will have to interface with very different interlocutors. Therefore, while the augmentation of a task may enable its automation over time, such automation may trigger the augmentation of other adjacent tasks.

Whether it is automation or augmentation, notwithstanding all the positive outcomes associated with industrial robots and artificial intelligence, there are also some concerns about them. Indeed, not only are new technological advances radically changing the kind of jobs that will be needed in the future, but they are also shaping how, where, and who will do them, directly impacting the labour market. An overview of the literature and the corresponding empirical

[6] Managers (who are at risk of losing their jobs because of automation) will tend to favour augmentation, while owners (who are only interested in the efficiency and productivity of their company) will prefer automation.

evidence on the relationship between automation and key labour market indicators is then provided.

2.3. The theoretical model

The starting point is based on the fact that a final product is realized through the completion of a set of tasks, which can be performed by humans or capital. The choice between these two factors determines what (Acemoglu & Restrepo, 2019) call the task content of production. What is important to remember is that the range of tasks required to manufacture a product is not constant, but can change over time, giving rise to new factor allocations and consequently new task contents. The two authors present a specific framework to describe this situation and its related effects.

Consider a single-sector economy, where the output combines a specific set of tasks between N-1 and N, and whose midpoint is I. Since part of them will be realized by labour and part by capital, it is possible to state that tasks with $z < I$ are automated and can be produced with capital. Conversely, tasks with $z > I$ are not automated and can be produced with labour. It is therefore evident that an increase in N is associated with the introduction of new labour tasks, while an increase in I corresponds to the introduction of automation technologies (Figure 1).

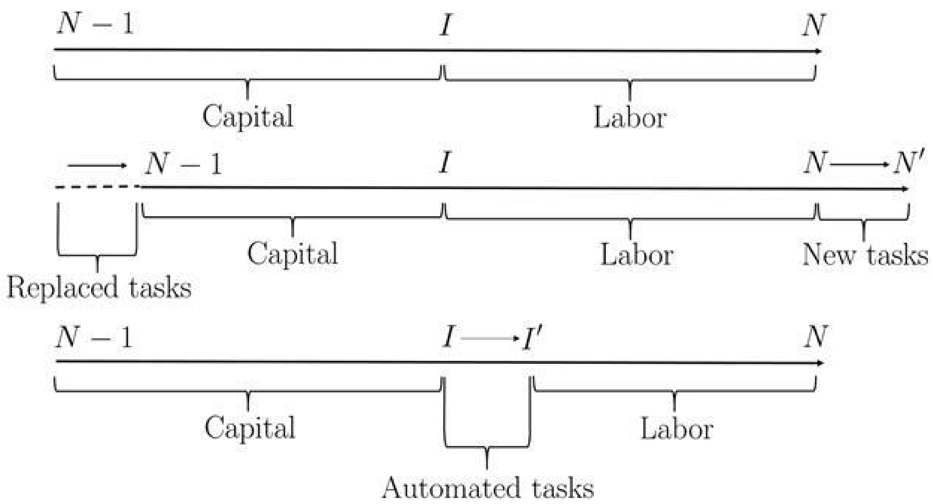

Figure 1: Allocation of capital and labour to the production of tasks and the impact of automation and the creation of new tasks.

The last condition described above clearly leads to a situation where artificial intelligence and robotics replace workers in the tasks they used to perform, thus resulting in the so-called displacement effect. Moreover, since the increase in output per worker due to automation is generally not accompanied by a simultaneous increase in demand for labour, the displacement effect also causes a reduction in employment and wages. Therefore, if this were the only effect taking place, it would mean that automation would always harm the labour market. However, as noticed in (Acemoglu & Restrepo, 2018), at least three countervailing forces are pushing against the displacement effect, which could even lead to an increase in labour demand.

The first one is the productivity effect, which stems from the ability of automation to simultaneously reduce the costs of performing a specific set of tasks and increase the labour demand in non-automated tasks. In fact, by substituting capital for labour, given the relative cost advantage of the former, a natural reduction in the average cost of production processes follows. This, in turn, results in products and services being cheaper than before, thus making households richer and increasing their demand for goods. As a result, economic sectors expand and the demand for labour in previously non-automated activities increases. The productivity effect can manifest itself in two ways: on the one hand by increasing the demand for labour in the same sectors that are being automated[7], on the other hand by increasing it in other sectors[8].

Closely related to the effect just described is the so-called deepening of automation. The insight comes from the evidence that automation does not always replace tasks previously performed by humans, but sometimes it merely increases the productivity of existing machines. Tasks that have already been automated are thus made more efficient, triggering a productivity effect without displacement.

The last one, namely capital accumulation, is less intuitive but equally powerful. It is based on the fact that automation, by increasing the capital intensity of production, in turn, triggers an increase in the demand for capital and thus causes its further accumulation. It is evident that if the long-run rental rate of capital relative to wages is sufficiently low, then the long-term equilibrium will result in the automation of all tasks. However, the greater the amount of capital used in an economy, the higher its rental rate and thus the greater the advantage of labour over capital.

The main problem with these countervailing forces is centred on the fact that, although they are all relevant, they are not yet strong enough to ensure a balanced growth path. In fact, with or without these forces, ongoing automation would still reduce the share of labour in national

[7] This aspect clearly requires the demand for products in these sectors to be elastic. It acts by reducing the relative price of products that are automated and restructuring production toward these sectors.
[8] This condition is also called the composition effect and captures the implications of sectoral reallocations.

income. However, leaving aside for the moment all discussions on the measurement of this variable, which will be further explored later in this work, the overall empirical picture looks quite different. Indeed, except for the last 30 years, the values were within the range of those observed in the past century. This evidence suggests that there was a more powerful force able to balance the effects of automation.

It is due noting that periods of rapid automation usually coincided with the introduction of new activities, tasks, and industries, which allowed people who had lost their jobs to find alternative employment. Therefore, the creation of new tasks in which labour has a comparative advantage over capital is deemed to be this "more powerful force" to balance the growth process: in the same way that automation causes a displacement effect, the creation of new tasks triggers a reinstatement effect. As a result, additional labour demand is generated, and its share in national income increases.

The interesting aspect of this condition is the endogenous relationship between new tasks on the one hand and automation, artificial intelligence, and robotics on the other. Indeed, not only does increased automation generate incentives for the introduction of new labour-intensive activities (as suggested earlier in explaining the capital accumulation principle), but also certain technologies such as AI may facilitate the emergence of completely new job categories. A study conducted by Accenture and published in (H. J. Wilson et al., 2017) identified three new areas: trainers (to teach AI how it should perform, make fewer mistakes and mimic human behaviour), explainers (to clarify and properly communicate the output of complex machine learning algorithms), and sustainers (to monitor the AI's adherence to human values and morals, correcting all undesirable results).

In conclusion, the final effect of automation on the labour market can be summarized as follows:

$$Final\ effect = displacement\ effect + countervailing\ forces + reinstatement\ effect$$

In addition to the just presented model, it is important to consider some challenges related to restoring the pre-automation levels of the share of labour in national income. Indeed, economic adjustment can vary widely depending on the different variables at play. First, as automation completely changes the task content of production, existing workers will have to reallocate to new job positions. This process is usually complex and slow because it takes time to find both new occupations and tasks in which the workers are productive enough. Indeed, a crucial problem is the mismatch between skills and technologies. Following an evolutionary path, new jobs will require new skills, and in case workers do not possess them, the adaptation process will be longer and more painful. In this regard, it is essential that education quickly adapt its programs and courses, otherwise the process will be further hampered. Finally, it is worth noting how the lack of required skills can be a problem not only in finding new employment, but also in effectively increasing the productivity of new technologies. In fact, if complementary skills are lacking, potential productivity gains will be limited.

Small productivity improvements can also result from so-so technologies, which threaten employment and wages much more than brilliant automation advances. This happens because productivity gains are not sufficient to counterbalance the decline in labour demand due to displacement. In fact, since the source of productivity gains is rooted in the ability of firms to use cheaper factors of production, these improvements will be proportional to the cost savings obtained in this case by substituting capital for labour. Therefore, the higher the productivity of labour relative to its wage in specific tasks, the lower the advantage of automation. So-so technologies generally provide very small cost savings, which therefore result in insufficient productivity to offset the negative effects of displacement. However, it is worth mentioning that the ultimate cause of productivity gains from automation lies not only in the level of wages but also in the amount of labour offered: when wages are high and labour is scarce, automation will provide a strong productivity effect. When the opposite condition applies, the contrary is true.

2.4. Empirical evidence on productivity, employment and wages

Although the effects of robots are among the most current and discussed topics in the economic landscape, only a few empirical studies have attempted to determine the overall impact of automation on productivity, employment, and wages. An important step in this analysis has been represented by the pioneering paper of (Graetz & Michaels, 2018), which focused on the variation in robot usage across 17 countries. Relying on the database of the International Federation of Robotics (IFR) (to which the EU-KLEMS database was added), they provided an interesting explanation of one of the key reasons behind the expansion of industrial robots. Specifically, they estimated that between 1990 and 2005 the price of industrial robots in the major developed economies decreased by about 50%. Furthermore, if quality improvements are also taken into account, the drop was even bigger: in 2005 it was possible to buy robots at a price approximately 75% lower as compared to fifteen years before. Consequently, it was calculated that the average robot density increased from 0.58 to 1.48, namely more than 150%. This, in turn, has resulted in an estimated increase in labour productivity of about 0.36% between 1993 and 2007. In addition to studying the effects on productivity, their research also challenged the concern that automation would have a negative impact on employment. In fact, their model demonstrated that an increase in robot densification had no significant implications on the number of hours worked.

Using an original database, (Cette et al., 2021) extended the above-mentioned results to a larger number of countries and over a longer period. Consistent with previous research, the analysis showed that in 30 OECD countries, between 1970 and 2019 the average contribution of robots to productivity growth was around 0.2% per year. Since this is an average measure, it is evident that some countries outperformed others; for instance, Germany and Japan showed values between 0.7% and 0.9% in the late 1990s, but these declined afterwards. The same path has been followed by several Eastern European countries in recent years. Focusing instead on the impact of robots with a narrower view, (Chiacchio et al., 2018) analysed six main European countries: Finland, France, Germany, Italy, Spain, and Sweden, which accounted for 85.5% of the EU robots market in 2007. Differently from the results described above, they found that one additional robot per thousand workers reduced the employment rate by a range between 0.16% and 0.20%.

In other cases, the estimate has been limited to one specific country. Among the most valuable is worth mentioning the study of (Acemoglu & Restrepo, 2020), where the focus was on the US market. The two authors started from the evidence that, between 1993 and 2007 there was an increase of one robot per thousand workers in the US. Since they wanted to understand the impact of automation on the national labour market, they collected data from the IFR on the use of robots across 19 industries. However, as the IFR database lacks regional detail, they decided to assign the robot share to different commuting zones based on the distribution of employment. Through this methodology, they documented that, despite the positive correlation with labour productivity, one more robot per thousand workers reduced aggregate employment by about 0.2%. This result implies that one more robot installed in that period reduced employment by about 3.3 workers. However, it is worth noting that this estimate includes both direct and indirect effects, the latter being represented by a lower demand for non-tradable goods because of a lower employment rate and thus lower disposable income.

The same approach has been implemented by (Dauth et al., 2021), who studied the adjustment of German local markets to industrial robots. According to their findings, between 1994 and 2014 industrial robots had no negative impact on employment, thus confirming the conclusions of (Graetz & Michaels, 2018). These results seem to contrast with those proposed by (Acemoglu & Restrepo, 2020), who evidenced a negative effect of automation on employment. The solution to this problem comes directly from the theory that these latest authors proposed and that we summarized above with a formula. Specifically, whereas in the US case the countervailing forces and the reinstatement effect were not so strong to counterbalance the displacement effect, in Germany the opposite happened. Indeed, as it emerged in this latter case, industrial robots were responsible for the reduction of jobs in the manufacturing sectors, but the final effect on employment was not negative due to the creation of new jobs in services.

In addition to studying the overall impact of automation on employment, some researchers have tried to investigate its effects on a deeper level. For instance, notwithstanding the missing evidence of robots effectively reducing employment, (Graetz & Michaels, 2018) differentiated the effects undergoing different categories of workers, finding that automation had a negative impact on the share of hours worked by low-skilled workers. While for these latter the evidence was large and statistically significant, for middle and high-skilled workers it was positive but imprecise.

In contrast, analysing the dynamics of ten major occupational groups in the US between 1979 and 2012, (D. H. Autor, 2015a) discovered that employment decreased for middle-skilled workers but increased both for low and high-skilled ones, thus leading to the so-called job polarization. Moreover, it was noticed that this phenomenon of routine-biased technological change (RBTC) did not seem to involve only the US but also many European economies (Goos et al., 2014). The main explanation provided to account for this shift was rooted in the fact that most middle-skilled jobs consist of repetitive, well-specified activities in an unchanging environment. Therefore, computers and robots could have codified and automated these kinds of "routine, task-intensive occupations", performing them in place of humans. This outcome was also confirmed by (Chiacchio et al., 2018), who found the same pattern. In the six European countries they analysed, they observed that between 1995 and 2007 employment grew stronger for technicians, associate professionals, and some elementary occupations, whereas it decreased for plant and machine operators.

Since comprehensive data availability represented a problem for the consistency of the aforementioned studies, it has been deemed worthy to refer to the more recent and complete study carried out in (de Vries et al., 2020). The authors combined data on robot adoption and employment, covering 19 industries in 37 countries between 2005 and 2015. Examining the impact of robot adoption on tasks, they built a framework distinguishing between routine versus non-routine and manual versus analytic tasks. It was found that, on average, routine manual employment decreased by 4% in almost all the countries observed, although the magnitude of this fall differed across countries and industries. However, this decline was completely mirrored by the growth of non-routine analytic jobs, which increased by the same percentage amount. This final result may be in line with the prediction of (D. H. Autor, 2015a) for the future, since in his opinion a significant amount of middle-skill jobs will persist in the next decades. The underlying assumption for this condition to realize is that these kinds of job will combine routine technical tasks with some other tasks in which workers have a comparative advantage, such as adaptability, interpersonal interaction, and problem-solving. In this scenario, vocational education and job training systems will be key in providing the exact skills that will be needed for these new jobs.

Another interesting point that is often cited is related to the different impacts of automation on employment in advanced and developing countries. This point was only partially explored by the previously mentioned study of (de Vries et al., 2020), whose results were valid for high-income countries but not for emerging market and transition economies. One possible explanation may be related to the higher level of wages in developed countries, which increases the incentive to replace workers with robots. Differently, although considering a very similar amount of countries and sectors over the same period, (Carbonero et al., 2020) concluded that the overall drop in employment was very low in advanced economies (0.43%), while rather pronounced in developing countries (11%). The discrepancy between these two research is imputable to both the different sources of industry-level information and to the broader focus of the second study compared to the first, which was solely centred on routine jobs.

Moreover, automation has been observed to also reverse the trend of offshoring production from advanced to low-income countries. Indeed, advances in robotics will increase the attractiveness of producing domestically, resulting in reshoring activities: in addition to displacing national workers, automation can also displace foreign workers. This intuition was confirmed by (Faber, 2018), who analysed the impact of robots adoption in the US on the employment of workers in Mexico, which is its second key importing country[9]. The results showed that exposure to foreign robots caused a robust negative impact on Mexican workers, directly reducing the amount of exports to the United States between 2000 and 2015. In terms of quantitative magnitude, it was calculated that Mexico saw a reduction of about 1.7 million jobs, namely around 11 workers for each additional robot installed in the US.

One last point that should be covered is related to the evidence in terms of wage changes, which is extremely important as it directly links with the broader theme of inequality. Notwithstanding the above-mentioned study of (Graetz & Michaels, 2018) documented a small but positive effect of automation on wages between 1993 and 2007, (Acemoglu & Restrepo, 2020) observed a significant decline of 0.42% in the wage of US workers over the same period. Moreover, they

[9] According to the OEC database, US' main importers in 2020 were China, Mexico, and Canada, with percentages of respectively 19.5%, 14.5% and 11.8%.

determined that the negative effects were concentrated on the bottom and middle part of the skill distribution, thus raising inequality concerns. In this regard, an interesting topic that is often discussed concerns whether wages followed the same polarization trend of employment. The answer has been found to be generally negative for the EU countries, as wages increased significantly for high-skilled professions but also for middle-skilled workers compared to the low-skilled part of the distribution (Chiacchio et al., 2018), (D. H. Autor, 2015a). In a recent paper, (Acemoglu & Restrepo, 2021) provided a deeper understanding of this phenomenon, at least for the US economy. In fact, they documented that much of the change in the wages of local workers was determined by the automation of certain tasks in specific industries: those who were not displaced from the activities for which they had a comparative advantage experienced significant wage growth, while the others were subject to stagnant or declining wages. In particular, the authors estimated that between 50% and 70% of the observed changes in wage structure from 1980 to 2016 could be attributed to the displacement of workers who specialized in routine tasks in industries that faced a decline in labour share. In other words, there were winners and losers from the adoption of robots.

As emerges from the research just presented, individuals in the lower end of the skill distribution will tend to be left behind. Specifically, since further advances in R&D will enhance the income of the upper classes and thus generate wealth inequality, by extending the model it is easy to outline a clear pattern that will lead to increasing involuntary unemployment of low-skilled routine workers (Prettner & Strulik, 2020). Policy consideration will therefore be necessary, as will be stressed later in this work.

2.5. Automation anxiety

As discussed above, although there is evidence that automation is not always associated with negative effects on the main variables of an economic system, or at least with all its sectors and workers, the anxiety associated with the most recent technological advances is still very high. This feeling has an important history, as it first arose in the 19th century when a group of English textile workers, better known as "the Luddites", protested against the mechanization of the industry in which they were working by directly destroying some of the machines. Only a few years after the Second Industrial Revolution, (Keynes, 1930) coined the term "technological unemployment", referring to the "*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*". This condition, although being considered only a temporary maladjustment phase, raised many concerns that most jobs would soon disappear without the economy effectively offering alternative occupations. One reason behind this misconception is the so-called lump of labour fallacy, the assumption that there is only a limited amount of work to be done: if an increasing number of tasks are automated, employment will reduce.

The concern that new technological advances will harm a substantial proportion of workers is linked to the so-called "paradox of abundance". Indeed, increased task automation causes an increase in labour supply, posing a threat of excess rather than scarcity. As pointed out by (D. H. Autor, 2015b), given that most people in market economies rely on their scarce labour as their primary source of income, if rapid technological advances effectively replaced cheap and abundant capital for scarce and demanding labour, society would become richer, not poorer. However, as he observed, "*this capital-based technological progress would create a substantial income distribution problem: those who possess labour but not capital may not have the means to live adequately*". In other words, the issue is more distributive than technological (Akst, 2013).

It is evident that recent progress in the fields of computing, AI, and robotics carries the risk of labour substitution to a much greater extent than in the past. Indeed, advances in technologies, such as algorithms for big data and advanced robots, are progressively replicating an ever-increasing amount of human capabilities, thus posing a serious threat to both non-routine cognitive and manual tasks[10] (Frey & Osborne, 2017). In this regard, (Acemoglu & Restrepo, 2017) developed a task-based model in which both low and high-skilled workers compete against machines. While the former consists of a well-known phenomenon, the latter is related to a new hypothetical phase of automation involving the possibility for machines to specialize in jobs requiring human judgement, problem-solving, and other specific soft skills. The authors showed that although the final impact of automation on wage changes is ambiguous, at the same time its net effect on inequality is very clear: "*low-skill automation always increases wage inequality, whereas high-skill automation always reduces it*".

Finally, the recent Covid-19 global pandemic has accelerated the course of automation, but its effects on the economic system have not yet been assessed. In this scenario, the real question is whether creative destruction will still take place and be effective, meaning whether the creation of new jobs will compensate for the loss of other jobs.

[10] According to the research carried out by the cited authors, around 47% of total US employment is at risk of being automated in the next decade or two.

The next chapter will address the first research question this work will try to answer, namely whether the rather stable level exhibited by the labour share of income over the last century is turning towards a consistently downward trend in recent years. Moreover, among the various possibilities, it will be investigated whether technological development can be regarded as the main cause of this phenomenon.

3. THE IMPACT OF AUTOMATION ON THE LABOUR SHARE OF INCOME

The first step in understanding how strongly the economic environment has been affected by automation is to analyse the distribution of national income between capital and labour. Given that national income can be defined as the sum of all income earned by a given country from the goods and services it produces in a given year, the labour share is the portion of national income attributed to workers, while the capital share is the corresponding portion attributed to capital. Having outlined a theoretical model for automation in the previous chapter, it is now interesting to investigate whether, in practice, the displacement effect has been counterbalanced by the sum of the countervailing forces and the reinstatement effect. Therefore, the objective of this section is to determine the evolutionary path of the aforementioned income distribution share between labour and capital, estimating the former and deriving the latter. In particular, after some measurement considerations, the main variables at play will be analysed and the causes and consequences of the observed phenomena will be described. Particular attention will be devoted to investigating the role played by technological development. The analysis will focus mainly on selected OECD countries in aggregate, while data on Italy will be presented separately, as the latter will be the main subject of the final sections of this paper.

3.1. The measurement debate

The measurement of the labour share of income has always represented an interesting topic in the field of academic research, but in recent years it has also captured the attention of the political debate. Indeed, the theory according to which "*the share of wages in output remains constant*" (Kaldor, 1957) seems to be far from describing what is currently emerging from a growing body of evidence: not only has labour share shown a downward trend in the last decades, but it also looked like a cyclical phenomenon. Nevertheless, the measurement of this important indicator is not as simple as it may seem at first glance; although the intuition is straightforward, there are differences due to the variables used and the way they are combined, such that a distinction is made between adjusted and unadjusted labour shares.

The unadjusted labour share of income (LSI) is generally computed as the ratio of total compensation of employees (wages and salaries before taxes, plus employers' social contributions) over a national product or income aggregate:

$$Unadjusted\ LSI = \frac{compensation\ of\ employees}{aggregate\ economic\ output}$$

Challenges concern both the numerator and the denominator. Regarding the former, the main problems consist in the definition of who should be classified as an employee and what should be counted as compensation. Concerning the latter, the main issue regards the chosen measure for the aggregate economic output (Gross National Income vs Gross Domestic Product). In any case, however, the unadjusted labour share is an underestimation of the real value, since compensation of employees does not include the "mixed income" from self-employed people. Moreover, as self-employment accounts for a large part of the labour force in most economies, the need for adjustment is even higher. Consequently, several countermeasures have been adopted to ensure that this value is regarded not only as capital income, but also as remuneration for labour input.

Following this logic, several institutions have started producing estimates of the adjusted labour share. Among the most relevant, it is worth mentioning the annual macro-economic database (AMECO) of the European Commission's Directorate General for Economic and Financial Affairs, which provides data for many developing and developed countries over a period of up to sixty years. In their results, the labour share of income is computed by dividing the total adjusted employment over total economy GDP and multiplying this ratio by the compensation per employee. Since the measure is available both at factor costs and market prices, it has been deemed more appropriate to use the first one, as it directly relates to the production of goods and services without including other items such as indirect taxes. Indeed, these elements should be removed from the aggregate income since they do not represent any kind of return on property or capital (Guerriero, 2012).

$$Adjusted\ LSI = \frac{total\ workforce}{GDP - indirect\ taxes + subsides} \cdot compensation\ per\ employee$$

Therefore, by selecting nine countries and computing their labour shares from 1960 to 2020, it emerged that their aggregate value decreased from an average of 69% to 63%. This decline was even more pronounced in the case of Italy, which fell from a value of 77% to 60% (Figure 2: Average labour income share in selected OECD countries and Italy between 1960 and 2020. Note: the selected countries are Australia, Canada, Germany, France, Italy, Japan, Spain, the United Kingdom, and the United States.
Source: AMECO database).

Figure 2: Average labour income share in selected OECD countries and Italy between 1960 and 2020.
Note: the selected countries are Australia, Canada, Germany, France, Italy, Japan, Spain, the United Kingdom, and the United States.
Source: AMECO database

Another relevant source of labour force data is represented by the International Labour Organization (ILO). According to one of its latest publications[11], there are two main methods that can be implemented to adjust the labour share of income. The first is based on splitting the mixed income between capital and labour using a rule of thumb or making other general assumptions, while the second involves adjusting labour income according to the compensation of employees and the self-employment rate in a given economy. Consistent with this second approach, after an intensive data collection process, a database with very accurate information covering the period 2004-2019 was produced. Further elaborating on these data, it was immediate to confirm the trend shown before: in the last few years, the labour share of the same previously selected countries saw a general decline, passing from a value of almost 61% in 2004 to one of 59% in 2019. However, quite surprisingly, Italy seems to have performed very well, especially in the last five years considered (Figure 3).

[11] The Global Labour Income Share and Distribution, 2019.

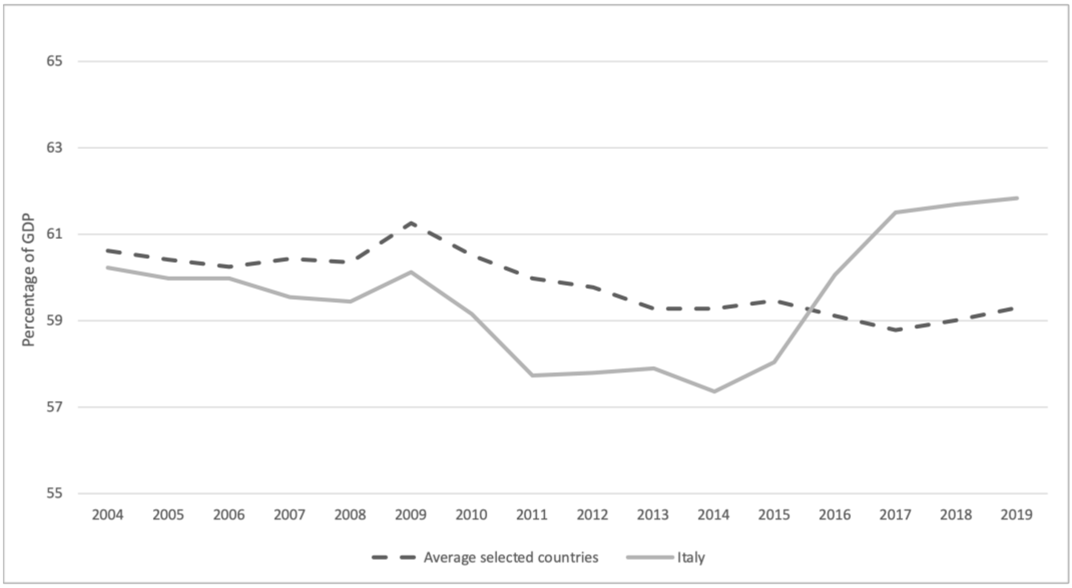

Figure 3: Average labour income share in selected OECD countries and Italy between 2004 and 2019.
Note: The selected countries are Australia, Canada, Germany, France, Italy, Japan, Spain, the United Kingdom, and the United States.
Source: ILOSTAT database

Although differences in the way adjustments are made may influence the magnitude of the observed phenomenon, they generally do not affect the overall pattern. Indeed, both Figures 2 and 3 show a countercyclical behaviour of the average adjusted labour share: during the oil crisis of 1973 and the financial crisis of 2008, the long-term downward trend of the indicator was temporarily interrupted and slightly reversed, though it resumed a few years later. Finally, it is worth noting that the two approaches just presented are in line with the one proposed by (Guerriero, 2012), who assessed the quality of very different measurement methodologies by directly comparing the rationale behind them.

An aspect to bear in mind is the fact that what happens at an international level does not necessarily reflect what is occurring in a specific nation. Furthermore, the results presented by (Guerriero, 2012) pointed out the existence of contradictory evidence about the general level of labour share across different regions and countries. In fact, when considering unadjusted measures of labour share and limiting the analysis to the manufacturing sector, developed regions show a higher level of labour share. On the contrary, when including self-employment income and analysing the whole economy, the gap not only decreases, but also changes direction. This latter result is more in line with the human-machine race hypothesis, thus reinforcing the concerns expressed at the end of the previous chapter. Finally, the author found that the higher the level of industrialisation of a country, the lower the variance in the value of the labour income share. This effect can be due to either a measurement problem or a country's economic structure. In the first case, the issue is based on a different measurement accuracy of the variable; in the second, the intuition is that a greater presence of self-employed people in developing countries makes them easier and faster to adapt to changes in external circumstances.

3.2. Productivity and wages as key factors

Having observed the general pattern of labour share of income over time, it is now interesting to break down its constituents and to understand which are the drivers of such a result. Starting from the formula of adjusted LSI described above, it emerges how the main determinants of the economic indicator can be identified in labour productivity and average wages. Indeed, as discussed in (Walsh, 2004), labour productivity (which can be defined as the real economic output per hour of work) has an impact both on the level of employment and the potential GDP. However, to understand its ultimate impact, it is important to distinguish between micro and macro-economic perspectives on the one hand, and between short and long-term effects on the other. On the one hand, as observed in explaining the Acemoglu and Restrepo model in the previous chapter of this work, increased productivity and technological innovations are causing structural changes at a micro-level, with some industries shrinking and others expanding. As a result, the final impact on overall employment observed from a macro perspective may hide the underlying internal forces, with many jobs disappearing and being created repeatedly each year. On the other hand, the question faced by macroeconomists concerns whether a higher level of productivity can produce other aggregate effects than simply shifting the share of workforce employed in the different industries.

To address this issue, it is key to consider the difference between the short and the long run. Indeed, if there is an upturn in the demand for products, firms respond by increasing their production. Clearly, if labour productivity remains constant, a company will need a larger number of employees to expand the amount of goods or services it offers. However, as productivity levels improve, the company will be able to meet the new demand using the same number of workers or even reducing it. The same result holds in the case in which demand is stable while productivity has grown. Therefore, while in the short-term there might be different employment outcomes depending on the way variables interact with each other, in the long term the focus is unique and there is no uncertainty. In fact, according to this perspective, higher productivity always increases potential GDP, since it lowers labour costs and favours the creation of new industries. This, in turn, will have a positive impact on employment: if labour is cheaper, firms will find it profitable to hire additional workers; if new sectors emerge due to technological innovations, people will find new job opportunities. Finally, as firms compete to hire new workers, the increased demand for labour will tend to raise wages.

As can be seen in Figure 4, this trend was also confirmed by the OECD data. In fact, using 1995 as the base index, it is demonstrated that in the nine selected countries employment and labour productivity increased at very similar growth rates. However, the situation appears to be completely different in the case of Italy, where since 2000 employment has increased much more than productivity, which has instead remained rather constant. This suggests that lower productivity jobs are driving employment growth in the country.

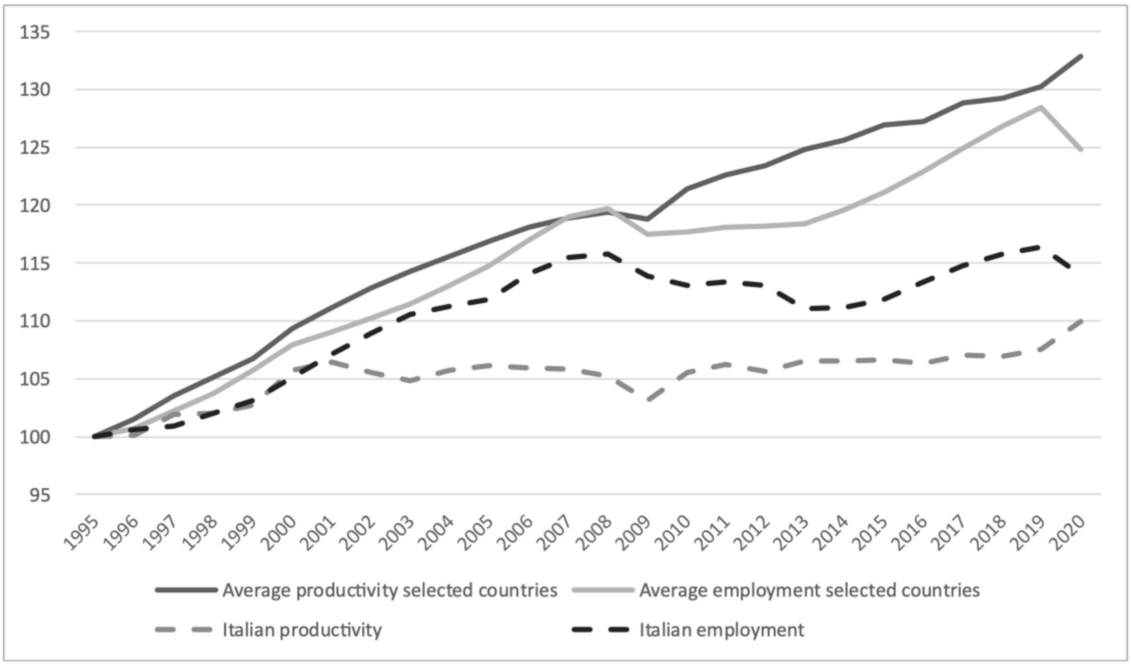

Figure 4: Indexed average growth of productivity and employment in selected OECD countries and Italy between 1995 and 2020.

Note: The selected countries are Australia, Canada, Germany, France, Italy, Japan, Spain, the United Kingdom, and the United States. Index is based on 1995 because of data availability.

Source: OECD database

The final effect on labour share, which varies depending on the combination of the two variables mentioned above, namely productivity and wages, has long been documented in the literature. In most cases, when average wages grow more rapidly relative to labour productivity, the labour share increases; conversely, a decline in the labour share often reflects a higher growth in labour productivity with respect to average labour compensation. In addition, these two variables have proved to be highly interdependent, such that faster productivity growth has almost always been linked to rising wages and improved living standards. Given the evidence of a steady growth in labour productivity and a gradual decline in the labour income share over the last decades, a corresponding slowdown in the rate of wage growth should be expected. To demonstrate this, the calculations have relied on the OECD database, which provided all the necessary components for an appropriate economic measure. Labour productivity, as in the figure above, has been calculated as the ratio of GDP to the total number of hours worked, while real wages have been computed by dividing the compensation per employee by the Consumer Price Index (CPI). To make the comparison possible, also taking into account the availability of data, it was decided to opt for indexed measures with 1995 as the base year.

The results showed, as hypothesised before, that in the nine selected countries where the labour share declined, average compensation growth lagged behind average productivity growth. However, as far as Italy is concerned, productivity and real wages growth really mirrored each other, although not always following the same path (Figure 5). This evidence might explain the ILO findings, according to which the labour income share in Italy has shown a rather unstable trend, falling more than the average after the 2008 crisis and exceeding the average from 2015 onwards. Moreover, it is worth noting that the changes in labour share are not only the result of differences in within-industry average growth between real wages and productivity, but may also result from the reallocation of workers towards or away from industries characterized by high levels of labour share. Finally, the correlation between growth rates and the relative levels of wages and productivity in an industry may play an important role. Specifically, if wages differ across industries, and the highest growth occurs in high-wage sectors, aggregate wage growth will be faster and, other things being equal, the labour share will increase. The opposite holds for productivity.

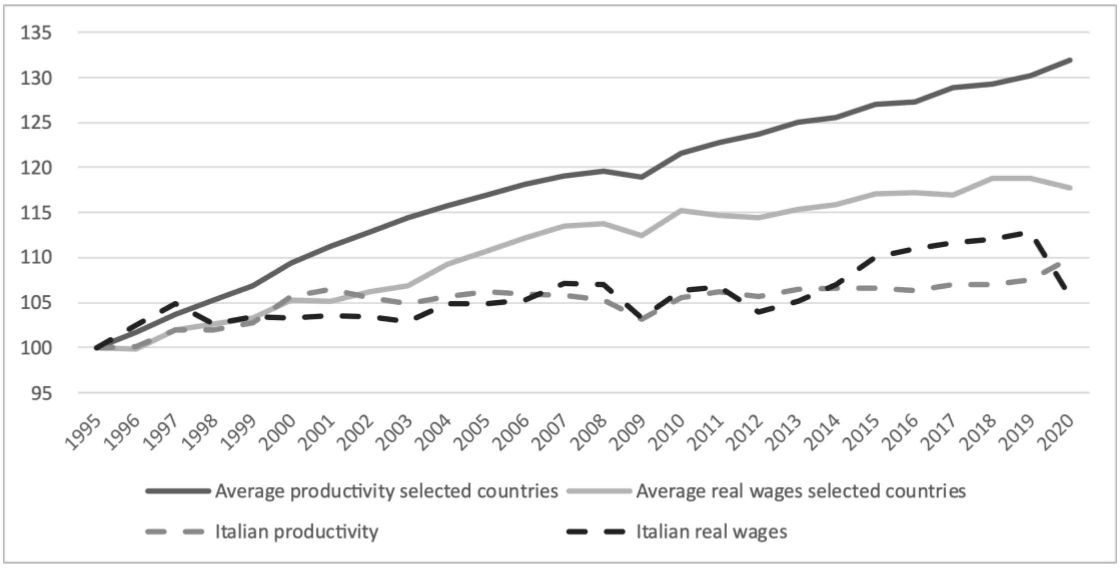

Figure 5: Indexed average growth of productivity and real wages in selected OECD countries and Italy between 1995 and 2020.

Note: The selected countries are Australia, Canada, Germany, France, Italy, Japan, Spain, the United Kingdom, and the United States. Index is based on 1995 because of data availability.

Source: Author's elaboration on the OECD database

3.3. Possible determinants of change

There are several reasons that could have determined the above-described evolutionary pattern of the labour share of income. Among the most relevant, it is due mentioning globalization, institutional factors, industry concentration, and technological change. However, although the first two elements may represent important forces, the evidence supporting them is too limited, for which reason only a brief description of them will be provided. Indeed, both because of data availability and the purpose of this work, the main analysis will regard industry concentration and technological developments.

Regarding globalization, most studies have found a general negative effect on labour share, especially in high-income countries. In fact, according to the theory, the opening to global markets causes developed countries to specialise in capital intensive industries, thus reducing the returns to labour. Therefore, provided that the elasticity of substitution is less than one, the share of labour will be driven downward (Guscina, 2006). The predictions of the model may be more complex when considering a heterogeneous labour force, as the final impact will be determined by the sum of the relative elasticities of substitution belonging to low and high-skilled jobs. However, contrary to what could be expected, (Perugini et al., 2017) have shown that globalization affects the labour share regardless of the skill profile of a company's workforce.

On the other hand, concerning institutional factors, the main measures discussed have been union density, minimum wage legislation, and other intermediate institutions such as employment protection legislation and unemployment benefits. The documented decline in union density[12] caused in many developed economies a reduction in employees' bargaining power, resulting in a lower possibility for them to negotiate better contracts providing a larger share of productivity growth as labour compensation. In addition, unemployment benefits have increased workers' reservation wages, namely the minimum amount they would accept for a given job, thus adversely affecting firms' demand for labour. Further empirical evidence is needed to determine the impact of the other forces mentioned above. However, as documented by (Deakin et al., 2014), the aggregate effect of institutional factors is to be considered overall positive, since labour share would have fallen faster had it not been for the effects of labour laws protecting workers.

Another cause that may explain the observed decline in labour share and that has been deemed worthy of further investigation is industry concentration, and specifically the theory of "superstar firms" proposed in a recent work by (D. Autor et al., 2019). This model, as will be seen, is related to almost all the previously mentioned drivers of change and is based on the "winner take most" approach, namely the idea that each industry is characterized by a small number of firms capable of capturing a very large market share. The reasoning behind this hypothesis stems from the evidence that changes in the economic environment tend to advantage the most productive firms within a sector. As a result, product market concentration will increase, as well as the share of value added reserved to this niche of companies. These superstars will thus experience a growth in profit margins on the one hand and a decline in labour shares on the other. However, there could be several reasons for this situation to occur. First, consumers may have become more sensitive to quality-adjusted prices, either because of globalisation (causing greater competition among products) or because of more efficient search technologies (triggering greater availability of price comparisons). Second, scale may give large firms an advantage in adopting intangible capital and information technology, especially if the fixed cost is high or if the marginal cost of adoption is positively correlated with firm size. Third, strong network effects could provide another explanation for the dominance of companies such as Amazon, Apple, Facebook, Google, and many other technology-driven firms: the value a user derives from a specific product or service depends not only on the direct utility of its use, but also on the number of other users who have access to it.

[12] Union density is computed as the ratio between the employed or self-employed people who belong to the trade union and the total number of wage and salary earners in the economy. One major reason for the observed decline in this indicator is imputed to the expansion in non-standard forms of employment.

Although the authors just mentioned focused mainly on the US, the results have been extended to other countries for which research has also been carried out. In general, it was found that concentration has risen across many OECD countries and that industries with the greatest emergence of "superstar firms" experienced the largest drop in labour share. Moreover, this decline was mainly driven by the reallocation of value added between rather than within firms, resulting in a higher size-weighted aggregate markup than the unweighted average. This evidence has been confirmed by (De Loecker et al., 2020), who documented how the distribution of markups has changed, with the median remaining constant whereas the upper percentile raising at an unprecedent speed. Furthermore, it was demonstrated that the price increase relative to marginal costs was much higher than would have been necessary to cover the rise in fixed and overhead costs: this would imply an increase not only in markups, but also in profitability. Since these increases were mainly due to a change at the top end of the distribution, it was concluded that this was evidence of greater market power. In terms of macroeconomic performance, it follows that an increase in profit margins often leads to a reduction in investment and expenditure on inputs such as labour.

Similar results have been found by (Barkai, 2020), who documented a negative correlation between changes in industry concentration and changes in labour share. However, the author developed an alternative approach to understand the decline in the latter variable. The intuition is based on the fact that the capital share of income should be decomposed in capital costs and pure profits, the former being defined as the annual costs of using all the capital inputs, while the latter representing the amount that a company earns in excess of its production costs. Therefore, an increase in the capital share, computed as the ratio between capital costs and GDP, is a sign of a substitution of labour by capital inputs; on the other hand, a growing pure profits share, equal to the ratio of pure profits to GDP, is indicative of a decreased competition. The results show that the decline in capital share has been much more pronounced than that of the labour share: pure profits have risen dramatically since the early 1980s. Nonetheless, it is also due noting that these calculations present some limitations. First, as stated above, the measurement of the capital share may omit unobserved capital, which is likely to increase capital costs and decrease the profit share. Second, capital costs have been calculated using a required rate of return for each type of capital, which represents an important approximation. Finally, these results are only valid for the US, which may be characterized by different dynamics with respect to other OECD countries.

Nonetheless, most studies have identified technology as the main factor contributing to the decline in labour share; according to (Bassanini & Manfredi, 2014), total factor productivity

(TFP) growth and capital deepening accounted for about 80% of the within-industry contraction in 25 OECD countries between 1990 and 2007. The authors explained this result by arguing that the spread of information and communication technology (ICT) has made it possible for companies to produce goods and services at an unprecedent speed and reliability, thus boosting productivity and allowing a higher level of substitution between labour and capital. This was found to be extremely true especially for unskilled labour, while skilled workers showed greater complementarity with ICT equipment. As a partial proof of this, (Taniguchi & Yamada, 2022) studied the impact on the skill premium, meaning the level of wage inequality between the two different categories of workers. The prerequisite of the model is the fact that changes in the skill premium can be either related shifts in demand (due to technological developments) or supply (due to education advances). It turned out that while the proven complementarity between new technologies and high skills tends to amplify wage differences, increasing educational attainment tends to have the opposite effect.

However, when looking at the value of ICT investment relative to GDP in some of the previously selected OECD countries, the overall picture depicts a downward trend. Specifically, the average investment share decreased by about one percentage point between 2000 and 2011, showing a slight upturn only starting from 2015. Italy experienced a similar but less pronounced pattern, with a value in 2017 slightly lower than the one coinciding with the first year covered by the OECD data (Figure 6).

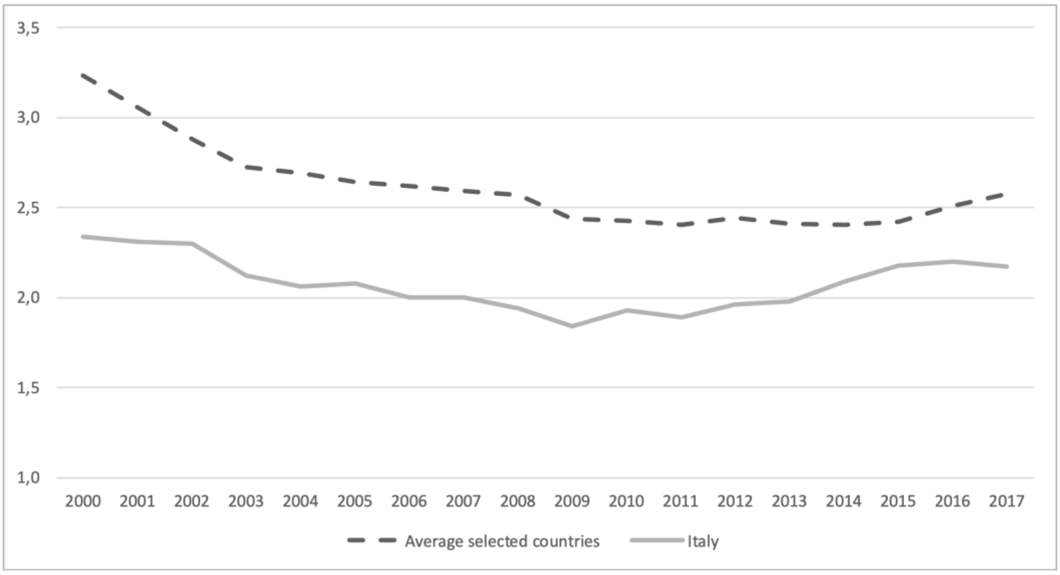

Figure 6: Average ICT investment as a share of GDP in selected OECD countries and Italy between 2000 and 2017.
Note: The selected countries are Australia, Canada, France, Italy, the United Kingdom, and the United States. Data from Canada are only available up to 2015.
Source: OECD database

Many researchers have explained these results by arguing that they represented a clear sign of the slowdown in digitalization. Nonetheless, further analysing the main components of this indicator, it emerged how the decrease in ICT investment over GDP was not a general phenomenon, as it effectively occurred for computer hardware and telecommunications equipment, whereas computer software and database followed a completely different trend[13]. In fact, this latter variable, which is more in line with the latest technological advances, remained almost stable throughout the period analysed, and even showed an upturn in the last years of the study (Figure 7). More interestingly, the volume of ICT investments increased during the same analysed period, thus signalling a possible hidden variable at play. Indeed, additional research pointed out that the price of all the above-mentioned components showed a general decline in the last decades, more pronounced in some countries, smaller in others. This intuition was also reinforced by (Garcia-Lazaro & Pearce, 2021), who claimed that the increased substitution of labour for capital had its main cause in the fall in the relative price of investment goods, although the most negative impact has been on low-skilled workers. This condition may be a further confirmation of the rise of the "superstar firms" mentioned above: while falling capital goods prices may have provided a greater opportunity to access new advances, the adoption of specific technologies such as automated production methods generally imposes huge fixed costs. Therefore, only larger companies will have a strong incentive to adopt them. In support of this, (Dinlersoz & Wolf, 2018) pointed out that more automated plants were characterized by higher capital share and labour productivity, but displayed a larger long-term labour share declines.

[13] It should also be noted that, while equipment and facilities have always been regarded as labour-enhancing technologies, the development of new types of capital, such as software and robots, is instead seen as a threat to labour.

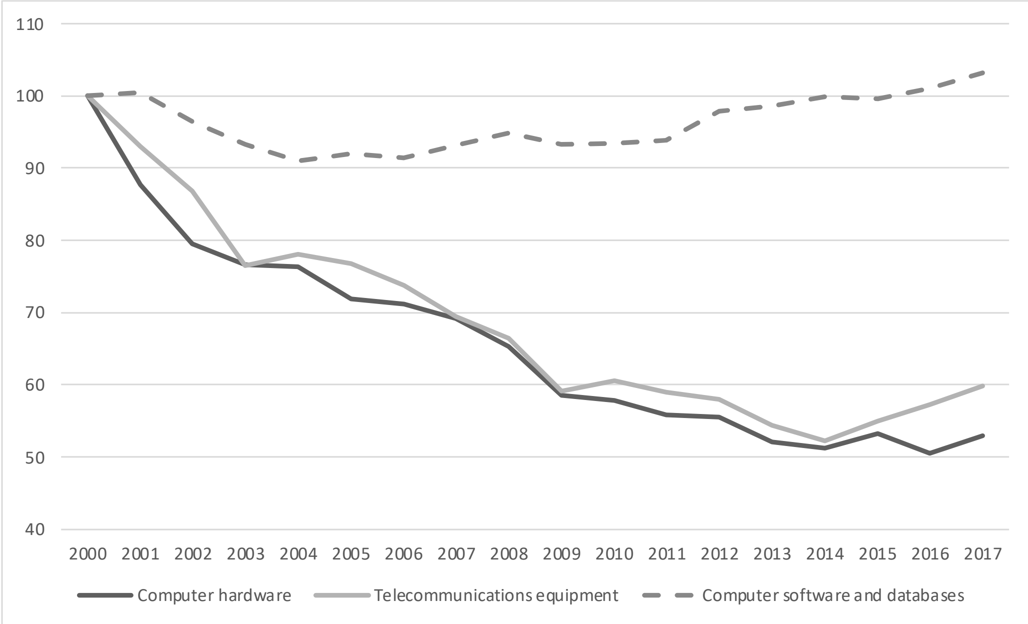

Figure 7: Average ICT components growth as a share of GDP in selected OECD countries between 2000 and 2017.
Note: The selected countries are Australia, Canada, France, Italy, the United Kingdom, and the United States.
Source: OECD database

Another possible hidden variable is related to the measurement of ICT investments in the Systems of National Accounts (SNA). According to SNA 2008, which is the current internationally accepted standard on how to measure a specific economic activity, there is a different treatment reserved to ICT investments. In fact, if a company purchases ICT equipment and this is used for more than one year in the production process, then the component is effectively recorded as an ICT investment. However, if the same purchase is embodied in a capital good not defined as ICT, the value of this indirect asset will not figure in the ICT investment. The adopted standard may thus lead to an underestimation of the real amount of ICT capital spending. Moreover, if the ICT embodiment grows over time, the final effect may become more misleading. As a matter of fact, if we also consider the value of the "indirect ICT assets" previously described, the average increase in the total value of ICT investment in the OECD countries reaches about 35% (Cette et al., 2019).

3.4. Main economic consequences

Despite the positive impact associated with the introduction of automation technologies and the corresponding increase in productivity, the fall in labour share brings many undesirable effects. The first is grounded on the fact that, consistent with the existing literature, labour productivity growth has caused an increase in the share of those possessing a tertiary education and a decline in the share of those with a lower level of education, specifically those who have not attended the upper secondary school. Since the level of education determines in most cases the amount of money one receives as work compensation, it is evident that the better educated receive a larger slice of the pie. However, this situation can lead to a drop in aggregate demand, due to the possibility that high-income households have a lower propensity to consume. In fact, they are deemed to save more with respect to their low-income counterparts. Therefore, if on the one hand the decrease of labour costs tends to rise firms' profits, on the other hand this increase is counterbalanced by a possible decrease in products and services consumption. Indeed, although higher profits may boost investments and thus the competitiveness of the company, a lower labour share could result in weaker purchasing power for the most active customers of the firm. It might be argued that by paying lower wages, firms could have a higher incentive to boost their investments, thus creating new job opportunities. However, in the group of selected OECD countries, the shift in the share of income in favour to capital has not produced the expected results in terms of investments. Specifically, between 1991 and 2020, while the capital share grew by about 10%, investment as a percentage of GDP exhibited a decline by almost 9%. This result seems to be consistent with the hypothesis of diminished competitiveness mentioned earlier, but further research on the topic is needed to confirm it.

There are two main motivations underlying the observed unequal trends of the two variables: on the one hand, the use of increased profits in developed economies has been generally directed towards the distribution of dividends and the investment in financial assets. On the other hand, productive investment in advanced countries has recently been hindered by weak household and stringent credit conditions. Finally, it is worth remembering that an economic landscape characterized by a declining labour share not offset by investment may give rise to a condition in which the country has to rely more on credit and exports to keep the level of aggregate demand constant. Luckily, this scenario does not seem to have occurred in the case of Italy, for which it is possible to notice a growth in investment much higher than the corresponding rise in capital share (Figure 8).

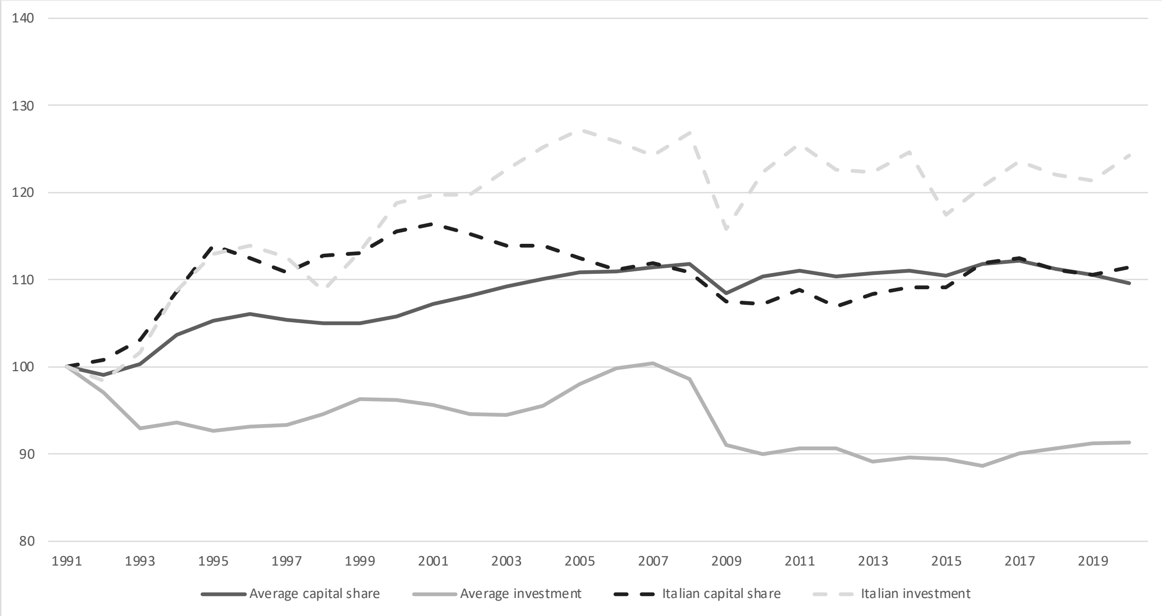

Figure 8: Indexed average capital share and investment in selected OECD countries and Italy between 1991 and 2020. Note: The selected countries are Australia, Canada, Germany, France, Italy, Japan, Spain, the United Kingdom, and the United States. Index is based on 1991 because of data availability.
Source: Author's elaboration on the OECD and AMECO databases

Another major consequence of the falling labour share is deemed to be the rising inequality between people offering their services in the form of labour and those whose contribution is mostly based on ownership. A special case in point is the self-employed, who are both employees and owners: even if their share of income as labour providers has decreased, the corresponding share as owners may have increased. However, this effect does not necessarily result in a situation where all workers become comparatively poorer and all capitalists richer; as stated before, it might be that highly skilled and educated workers experience an increase in their labour share and compensation. In support of these arguments, an OECD study discovered that, as far as Europe is concerned, the top 10% of income earners obtains 35% of national income. Moreover, as observed by (Atkinson et al., 2011), the increase in the top income share in recent decades was mainly due to the increase in upper labour income, in particular wages and salaries. Completing the picture, a study conducted by ILO[14] in 2011 found a decreasing labour share for low and medium-skilled workers, but an opposite trend for high-skilled ones.

An interesting way to understand to which extent inequality has influenced the decline in the labour income share is through a regression. Although it is based on only eight selected OECD countries and is not highly statistically significant, Figure 9 suggests that a negative correlation

[14] World of Work Report 2011: Making Markets Work for Jobs

between the two variables existed between 1991 and 2018. This means that an increase in inequality translated into a decline in labour share.

Figure 9: Percentage change in labour share over the Gini index in selected OECD countries between 1991 and 2018.
Note: The selected countries are Australia, Canada, France, Germany, Italy, Spain, the United Kingdom, and the United States. When the Gini index data for a specific year were not available, the one closest in time was used.
Source: Author's elaboration on the OECD and AMECO databases

Finally, as they are highly dependent on the level of inequality in a specific society, what needs to be avoided is the loss of social cohesion and civil unrest. Indeed, it has been demonstrated that an increase in nominal labour income, if accompanied by a decrease in the labour share, may generate social dissatisfaction. This dissatisfaction, in turn, generally reduces well-being and hinders social harmony, which are at the basis of economic growth (Briguglio & Vella, 2014).

4. INDUSTRY 4.0 IMPLEMENTATION AND ITS ENABLING FACTORS

So far, the present work has mostly focused on automation in general and ICT, which have represented two of the major technological developments in the industrial arena. However, as can be guessed from the first chapter, the final objective is to draw, even if at a preliminary level, some conclusions on the more recent phenomenon of Industry 4.0. Indeed, given its potential crucial role not only in the already described decline of the labour income share, but also in the delineation of the other main economic variables, it was deemed necessary to provide further information and insights. Therefore, a general overview of the adoption at the European level of the main technologies constituting the Fourth Industrial Revolution will be presented, followed by a digression on the different policies adopted by the main European countries. Subsequently, a list of the driving and hindering forces behind the implementation of Industry 4.0 will be offered, with a final discussion on two recent related phenomena, namely backshoring and sustainability of production.

4.1. The European panorama

In the last few years, the spread of new technologies under the name of Industry 4.0 has offered companies the opportunity to compete with each other in a completely different way. Indeed, not only do they have the possibility to improve on the internal side, implementing more efficient production processes and shaping new relationships with their employees, but also on the external one, being able to interact more effectively with suppliers and customers. However, despite being a relatively recent and widely discussed topic, data availability is still scarce. A lot of studies have in fact only investigated the functioning and the effects of the so-called "digital factory": an integrated production facility in which all processes are automated, information is shared, and human intervention is reduced to the minimum necessary. The factory is therefore defined as "*part of a larger ecosystem composed of several pieces*", as it enables machines and devices to communicate between each other and along the industry value chain (Castelo-Branco et al., 2019).

Quantitative research on the development of Industry 4.0 has proven to be a rather challenging process, as little evidence has been collected to allow a satisfying comparison across countries or industries. Two reasons might be related to this fact; on the one hand there could have been problems in defining what should be considered as a component of Industry 4.0, on the other hand there could have been a lack of collection of such information.

In fact, as is usually the case in economics, the implementation of new technologies and the associated data collection do not go hand in hand. The most reliable sources were found to be the OECD and Eurostat databases; however, for reasons of accuracy, only the second one was used in this work. Indeed, data from this latter source generally include Eurostat surveys, periodic studies by the European Commission (EC), and data from national authorities. Moreover, to remain up to date with the most recent applications, Eurostat has studied and covered new dimensions such as big data, cloud computing, and information sharing along the value chain. Therefore, the trade-off between larger amount of data and precision has been solved in favour of the latter element, focusing on the European landscape and specifically on those countries that were more suitable for a comparison with Italy. In particular, after selecting the most appropriate variables to document the implementation of the main Industry 4.0 technologies, it was decided to sum up the adoption rates to obtain an approximate digitization index for each country of interest and for the European Union as a whole. As can be seen in Figure 10, Germany had the best performance, with excellent levels of adoption in all technologies examined. Conversely, France and Spain ranked below the EU average. Finally, when considered in its aggregate, Italy seems to have scored well; however, when analysing the individual components, it is evident that its performance was biased by the high value of the Cloud category.

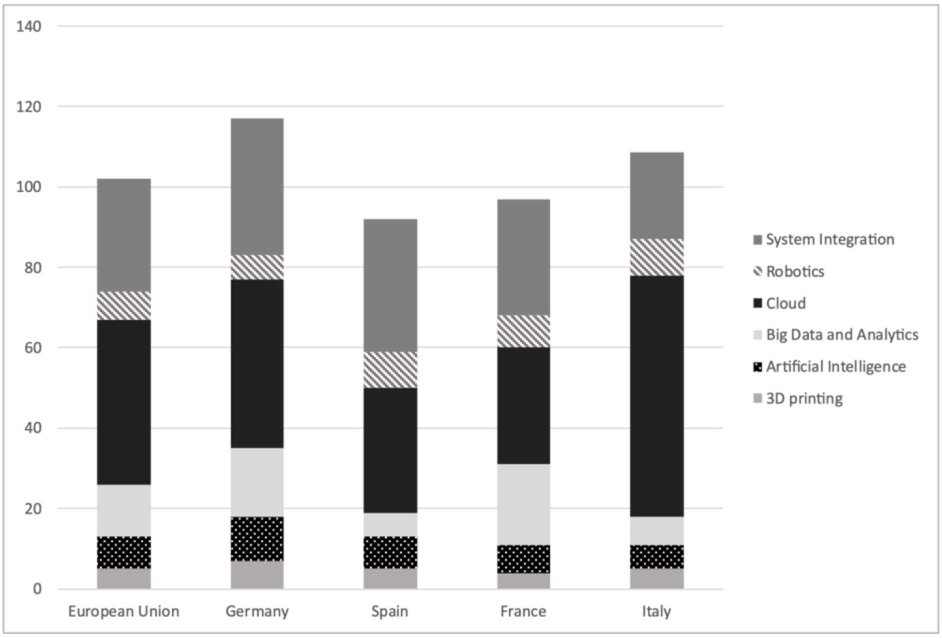

Figure 10: Adoption of Industry 4.0 technologies in selected European countries and Italy in 2020.
Note: When data for 2020 were not available, data from the closest year were used.
Source: Author's elaboration on Eurostat database

As mentioned above, it should also be noted that Eurostat itself has started collecting and reporting more and more updated data referring to the digitalization of European enterprises. Consistent with this, it has been developed a Digital Intensity Index (DII), a composite indicator that seeks to provide a measure of how deep the usage of different digital technologies across companies is. Data are derived from the survey on ICT usage and e-commerce in enterprises and regard different variables to which a value between 0 and 12 is assigned. This allows to distinguish between countries by classifying each of them into one of the four areas identified as follows: very low, low, high, and very high DII. The results of Figure 11 roughly confirmed the previous findings: Germany showed the highest value in the sum of high and very high DII, while France presented an above-average value in very low DII and a below-average value in very high DII. In addition, the distortion of Italy's value is evident, as the country ranked above the average in low DII and did not keep up with other countries in high and very high DII. In contrast, Spain completely reversed the previous evidence, passing from the worst performer to the one closest to Germany. This impressive change has probably been driven by the variables used in the computation of the Digital Intensity Index, which does not limit to Industry 4.0 technologies, but also includes other components such as web sales, social media, and CRM (Table 1).

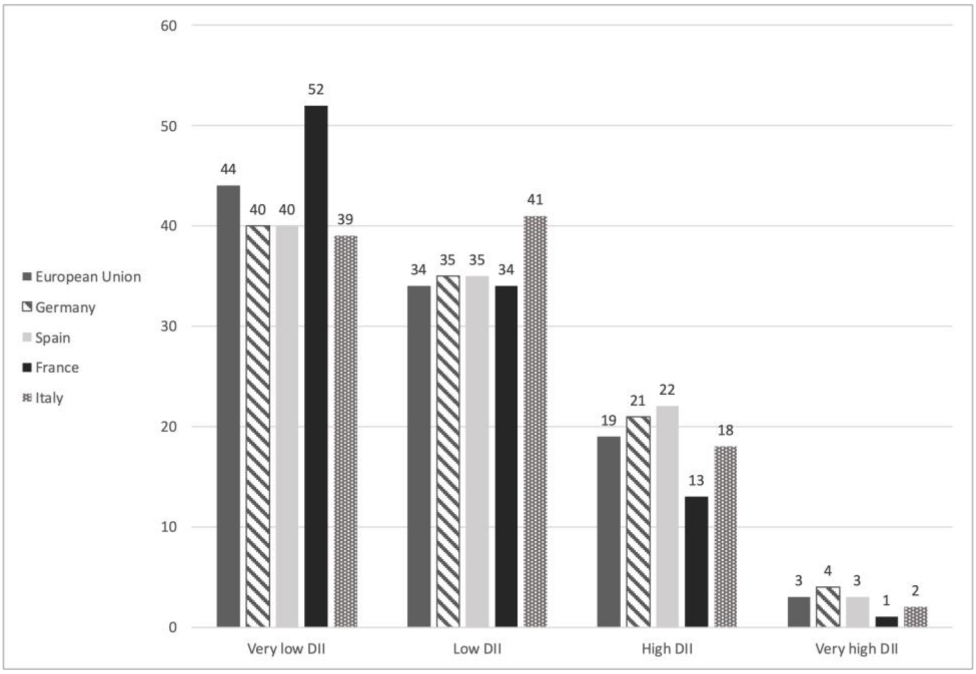

Figure 11: Percentage of companies with very low, low, high, and very high Digital Intensity Index in selected European countries and Italy in 2021.
Source: Eurostat database

Table 1: Latest Digital Intensity Index composition (2021)
Source: Eurostat database

DIGITAL INTENSITY INDEX v3 (2021)

The index is derived from the following features in:

		2021
DI3_INDEX	0-12	Give one point for each of the following 12 conditions, if true:
		Enterprises where more than 50% of the persons employed used computers with access to the internet for business purposes
		Have ERP software package to share information between different functional areas
		The maximum contracted download speed of the fastest fixed line internet connection is at least 30 Mb/s
		Enterprises where web sales were more than 1% of the total turnover and B2C web sales more than 10% of the web sales
		Use any IoT
		Use any social media
		Have CRM
		Buy sophisticated or intermediate CC services (2021)
		Use any AI technology
		Buy CC services used over the internet
		Enterprises with e-commerce sales of at least 1% turnover
		Use two or more social media

E_DI3_VLO	Enterprise has very low digital intensity index v3	Count of enterprises with points between 0 and 3
E_DI3_LO	Enterprise has low digital intensity index v3	Count of enterprises with points between 4 and 6
E_DI3_HI	Enterprise has high digital intensity index v3	Count of enterprises with points between 7 and 9
E_DI3_VHI	Enterprise has very high digital intensity index v3	Count of enterprises with points between 10 and 12

4.2. A comparison among public policies

Despite Europe is the place where the term has first been coined and used, the promotion of Industry 4.0 enabling technologies has been effective only starting from 2016. At the time, the primary reason for the increased attention received was undoubtedly the need to recover jobs lost due to countries with lower labour costs and taxes. Furthermore, due to a higher degree of specialization in high value-added activities, most advanced countries saw these new developments as a way to finally replace less skilled jobs where there was no comparative advantage. From the aggregate EU perspective, (Teixeira & Tavares-Lehmann, 2022) have classified Industry 4.0 both as a defensive strategy (aimed at preserving the essential role of manufacturing) and as a proactive approach (focused on boosting productivity and accessing new markets). However, for the project to be successful, it was necessary to define a coherent connection between the different national policies. In this regard, the European Commission together with the EU Member States launched in 2016 the "Digital Single Market", a framework designed to govern the coordination process. The following analysis will focus on the key aspects related to the policies implemented by the main European countries. The source is represented by the Digital Transformation Monitor, which aims to analyse the current level of technological development among European countries and its evolution over time. The reports used for the present analysis cover the period up to 2017.

Starting from Germany, which is considered the pioneer of Industry 4.0 in Europe, it emerges that the "Industrie 4.0" strategic initiative was supported and led by the public but implemented through dialogue with stakeholders. First, the government's budget of 200 million was supplemented by financial and in-kind contributions from industry. Indeed, Small and Medium sized Enterprises (SMEs) can obtain up to 60% of public funding, whereas, according to EU regulation, this percentage is reduced to less than 50% for large companies. The combination between public and private financing thus determined a mixed funding, which has typically provided a return of private to public investment ranging between two-to-one and five-to-one. Second, the target audience was represented by large companies, entrepreneurs and in particular SMEs in industrial sectors, but also policymakers. The common objective was to integrate advances such as Cyber Physical Systems and Internet of Things into the production process, promoting digital innovation and developing the ICT market. Specifically, the transformation of business models, and consequently of goods and services, was fostered by an important activity of research actors, together with experienced producers and pro-active unions. Third, in terms of implementation strategy, the agenda included as a core element the creation of an

I4.0 platform capable of connecting all the different actors and to facilitate the exchange of information. The continuous growth of members (which amounted to 150 at the launch of the platform) allowed to reduce industry segregation and to develop a reference architecture. Indeed, more than 15 million jobs in Germany are to some extent related to the production of goods, such that the new digital evolution may represent a very crucial opportunity for companies. BCG[15] has estimated productivity benefits to amount around $90-150 billion by 2025, complemented by other not easily quantifiable results such as network creation, information sharing, improved decision making, and better work-life balance. Indeed, the final goal of the project is to provide a reliable and consistent framework to "*boost international competitiveness of German production and better conditions for job creation*".

Given France's long-standing strength in innovation-based ecosystems and digital industries, the perceived obstacles for companies seeking to become more connected and responsive alerted the national economic system. Therefore, after having financed different initiatives fostering the adoption of new production technologies, in 2015 the government decided to launch a platform called "Industrie du Futur". This program has turned out to be very similar to the German one, since its main objectives were the coordination and the collaboration between industrial and digital stakeholders. Furthermore, although it was initiated and backed by the government, the initiative was mainly implemented by the private sector. Indeed, in addition to public funding such as subsidies and loans, industry and research projects could benefit from investments in R&D and production financed by the private. This condition was also evident from the allocated budget: approximately €10 billion has been provided by public sources (including some additional funding from 2017 onward), but all the public financing tools were conditional on private financing. For instance, the €650 million budget for technological offerings co-financed less than 50% of the specific private project, and the €5 billion available through tax aid for investments required a private financing of at least the same amount. In general, a private leverage effect of about five times is expected for SMEs, with a relatively higher ratio hypothesized for larger companies. Concerning the audience, the main targets were recognized in local companies (SMEs and mid-tier firms), technology providers, and public bodies. As in the German case, the overall objectives were identified as supporting the use of digital technologies, modernizing production processes, and innovating business models. For the project to be implemented, three enablers were considered essential. First, the involvement of key business, technology, and research stakeholders made it possible to find an

[15] Boston Consulting Group (2015) Industry 4.0: The Future of Productivity and Growth in Manufacturing Industries

agreement on the structure of the alliance. Second, the deployment of advanced manufacturing tools and new associated practices have been possible mainly through regional contribution. Finally, the commitment and political support shown during the different phases of the initiative, together with the strategic importance that has always been attached to it, played a key enabling role. Among the most relevant results, it is worth noting that up to 2017 more than 800 companies received loans, almost 3400 firms were supported with a diagnosis regarding their production processes and the way in which they could be improved, around 300 experts were identified, and 18 regions were involved. It is evident that new cooperation, additional funding, and other support activities will contribute to a greater extent to industry renewal, creating at the same time new sources of growth and job opportunities.

Built as a response to increasingly connected, demanding and competitive markets, "Industria Conectada 4.0" is a project developed by Spain to foster the digitization and the competitiveness of its industrial sector. Comparing the program with related policies in Europe, a crucial element of uniqueness emerges, namely its particular attention in directly supporting SMEs and micro-enterprises in the path towards digital transformation, sometimes even providing a personalized service. At the same time, in parallel with initiatives in other countries, although it was initially set up as a public-private partnership, the main role was assumed by the State, and specifically by the General Secretary of Industry and SME. Indeed, at the launch of the program, the government first allocated the largest amount of funds, i.e. €97.5 million, to finance innovative research projects in industrial companies. Moreover, both in the form of loans and direct aid, additional €68 million was provided for ICT companies, while €10 million was directed to innovative clusters. The overall financing was also complemented by €105 million allocated for Industry 4.0 by another public program and proprietary funds contributed by several external partners. In general, although the results at the time the EU report was published were not available, the government expected an average return of private to public investment of two to one. As could be seen from the destined budget, the target audience was mainly represented by industrial enterprises, specifically SMEs and micro-enterprises. Concerning the objectives, it is important to distinguish a threefold focus: first, to increase the industrial value added and the employment in its associated sectors; second, to define and develop a Spanish model for approaching the new industry; third, to improve local competitiveness and boost exports. However, it is important to note that, despite the effort toward the implementation of new technologies, the real focus was based on knowledge sharing and skill acquisition. To reach these objectives, the role of both intra and inter-enterprise enablers was key, as they were able to create collaborative environments and to stimulate the transfer of technologies between ICT and industry. Finally, since the initiative was effectively promoted somewhat later with respect to other countries, quantitative results were not yet available at the time of the EU report. Nonetheless, from a qualitative point of view, it was noted a high level of interest concerning the program, identified both through the questions asked on the website and the growing interaction with industry associations.

As far as Italy is concerned, the plan developed to keep up with the latest advances brought by the Fourth Industrial Revolution has been named "Industria 4.0". Its underlying strategy of supporting industrial change included several different measures, including investments in innovation, technology, and skills development. The plan was presented at the end of 2016 but was effectively launched only at the beginning of the following year. The amount earmarked by the Italian government for the development of the plan in the period 2017-2020 corresponded to €18 million. These funds were expected to generate private investment in the following years, both in the short to medium term through fiscal measures and in the long term through structural measures. Some examples of fiscal measures are hyper and super depreciations schemes, aimed at providing support for companies' tangible investments in technological advances and digital process transformation. In these cases, the purchasing costs are increased by respectively 150% and 40%, allowing higher deductions. On the other hand, for intangible assets and intellectual property, a special tax rate is applied (reducing income tax and regional tax up to 50%); likewise, tax credits amounting to 50% of costs are provided in the case of R&D activities (up to the annual ceiling of €20 million). There are also measures simplifying access to financing, such as the ones commonly known as the "Nuova Sabatini". Specifically, when applying for a bank loan of between €20.000 and €2 million to invest in new machinery, equipment, or other capital goods in the perspective of Industry 4.0 implementation, companies must be granted a payment contribution of between 2.75% and 3.57%. On the other side, concerning structural measures, it is due mentioning two projects with the objective of developing new skills. The first is the "Competence Centre", which provides training, best practices identification and advisory services for SMEs; the second is related to school education, with programs such as "Scuola Digitale" fostering the development of new abilities. Concerning the audience, no restrictions were made on size, sector, or location, such that companies could decide autonomously whether or not to benefit from the above-mentioned measures. However, since SMEs represent the building blocks of the country's economy, they were considered the main target group. In general, as stated before, the main objectives should be identified in the promotion of innovative investments and the empowerment of skills, aimed at boosting the competitiveness of Italian companies. This will be possible not only through higher flexibility and quality of production, but also through increased productivity and quicker processes. In terms of implementation, besides the increased fluidity of the process due to the absence of evaluation procedures, national communication and awareness activities represented crucial aspects. The expected results were quite ambitious: a €10 billion private investment increase over the following year was expected in the field of innovative technologies, a €11 billion private expenditure in R&D until 2020 and a growth in Industry 4.0 related education (more than 3.000 managers qualified in innovative topics and a double number of students attending vocational courses on I4.0). However, since the implementation of the project has only started very recently, there is little evidence of the outcomes obtained so far. The only data that emerge are related to the manufacturing industry, where it has been found a growing trend to acquire new machines and technologies as a result of the "Industria 4.0" plan.

4.3. Industry 4.0 driving forces and barriers

Despite playing a crucial role in fostering the development of Industry 4.0 in all industrial sectors, public policies alone are not sufficient to bring about a significant diffusion of the associated technologies. Indeed, there are several other factors that are encouraging companies to move towards the implementation of this new industrial approach. At the same time, however, it is possible to identify challenges that might hamper the adoption of new technologies, especially in manufacturing firms. Through a literature review, (Horváth & Szabó, 2019) defined a list of key driving forces and obstacles to Industry 4.0 implementation.

First, the growing trend towards globalization is enabling companies to constantly enter new markets, thus experiencing an international presence and increasing the competitiveness level. While, on the one side, lower concentration is associated with positive outcomes for consumers, on the other side, there is a risk that these benefits will not last for a long time, as only few companies will be able to win the global competition and gain size and power. However, as emerges from the economic theory, the final objective of companies is to make profits, so there will always be a firm trying to enlarge its market share and returns. It is evident that the only way to ensure this condition to occur is to develop a comparative advantage with respect to competitors. Therefore, new approaches are needed to speed up the production process, reduce the time to market, and ensure competitive production costs. Investments in digital technologies may help finding a balance between quality standards, quick product delivery, and fair pricing.

In addition, shorter product life cycles, together with changing consumer needs and preferences, have forced companies to redefine their industrial processes by combining a high level of dynamism and customer orientation. This condition, in turn, has determined a growing volatility in sales markets, which reflected in heavy fluctuations of orders, reduced delivery times, and lower ability to plan ahead. Remaining competitive in this scenario requires companies to increase the flexibility of plants, equipment, machines, but also material procurement along the entire supply chain (Bauer et al., 2015). It is evident that the centralized approach of order planning and scheduling, which is still used in some firms, is no longer adequate to respond to very rapid environmental changes. Indeed, not only it relies on forecasts (which are uncertain by nature), but it also requires expensive buffer stocks (which often lead to significant waste). A strategy based on lean production could offer a higher probability of success, as it ensures both the reduction of "muda" (waste) and the maximization of the value for customers.

However, to include this latter aspect among the enabling factors of the Fourth Industrial Revolution, the link between lean manufacturing and Industry 4.0 must be clarified. First, as stated before, lean management is an approach consisting of creating more value for customers using fewer resources. This is possible by essentially removing all activities that do not add value to the product, such as waiting, moving, and transporting. It is also concerned with ensuring a consistent flow of resources and avoiding overloading them, as typically happens in the case of over processing, over production, and buffer inventory. However, it is due remembering that lean does not imply the absence of inventory, it simply means reducing it by coordinating demand and supply in the best possible way. In addition, less inventory implies fewer defects, as a lean production approach makes it easier and quicker to identify possible problems. Performing a literature analysis, (Taghavi & Beauregard, 2020) discovered three different opinions about the interdependence between lean and Industry 4.0: lean is a basis for Industry 4.0; the two interact with each other; Industry 4.0 completes lean and increases its efficiency. Furthermore, (Bittencourt et al., 2019) determined that the two concepts, although with different origins and occasions, have the same objective: reduce costs and improve the productivity of firms. Therefore, they should be complementary, as the implementation of lean will determine the emergence of thinkers who, in turn, will foster the implementation of Industry 4.0.

Strictly linked with the above-mentioned factors, a final driving force behind Industry 4.0 implementation is business model innovation. Indeed, new technologies are expected to result in changes not only along the value chain, but also in the way value is created, enabling a higher level of customer involvement. (Prem, 2015) noted that the more products and services become digital, the more associated channels will tend toward digital transformation. In addition, being related to the underlying technology characteristics, a change in the relationship with consumers is expected. Specifically, new approaches will focus on open innovation with bidirectional communication regarding product and service design, but also on hybrid value creation[16] shifting from a product to a service-centric perspective (Servitization). According to (Frank et al., 2019), it is possible to build a conceptual framework to analyse the possibility of convergence between Servitization and Industry 4.0. As it emerges from Figure 12, on the vertical axis it is identified the level of Digitization, meaning the degree of implementation of the enabling Industry 4.0 technologies; on the horizontal axis it is displayed the level of Servitization, meaning the level of service dominance in the company. It is evident that Digitization is based on a technology-push logic, resulting in value added through the technical improvement of internal processes (cost reduction, flexibility, and productivity). On the other hand, Servitization is centred on the concept of demand-pull, as the value proposition converges on consumers (market expansion and customer loyalty). In this scenario, the author argues that it is possible to end up in a condition where firms have the possibility to benefit from both Industry 4.0 and Servitization. Indeed, although they are focused on different perspectives (internal and external), "*services can bring value to customers and, at the same time, they can become the channel of data and information gathering, aiming to foster a business feedback that enables internal improvements*".

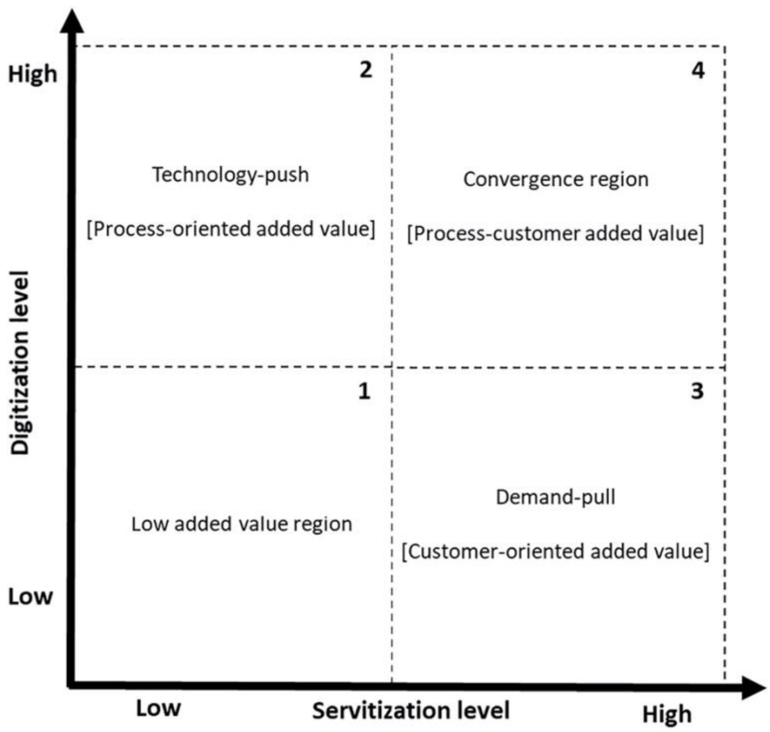

Figure 12: Innovation trajectories for Industry 4.0 and Servitization.
Source: Frank et al. (2019)

[16] The process of adding value through the innovative combination of products (tangible component) and services (intangible component)

On the other hand, there are also barriers related to the implementation of Industry 4.0. Most research agrees in classifying the lack of skilled labour, including the retraining of people to adapt to changing circumstances, as the biggest challenge. In fact, competence is described as a complex capacity of self-organization, consisting of several different classes: technical and methodological, social and communicative, personal, and activity oriented. The prerequisites underlying skilled work are represented by internalized values and rules in the form of feelings and motivations, while its associated outcomes are considered both efficient problem solving and continuous improvement (Adolph et al., 2014). Recent advances in manufacturing, focused on rising digital integration, have further intensified technical and organizational complexity, imposing significant changes especially on SMEs. Indeed, in the context of Industry 4.0, not only will the production process become increasingly decentralized, but it will also be automated, allowing it to respond autonomously to internal and external changes. Therefore, as time progresses, routine activities will become less and less relevant, as they will be entirely (or at least partially) replaced by machines; workers will progressively concentrate on innovative, creative, and communicative actions. Although learning factories have performed well in the past in training students and professionals (especially in the application of lean management), other competencies will be needed for the future of manufacturing. Indeed, (Erol et al., 2016) identified new skills required under the scenario of the Fourth Industrial Revolution, ranging from the ability to understand possible disruptions along the digitally integrated value chain to the flexibility with regard to working time, content, and location. Indeed, closely linked to this latter concept, another challenge from the perspective of companies is related to the personnel deployment strategy. According to (Bauer et al., 2015), other than flexible working times, firms are starting to implement other tactics to make employment and sales orders go as much as possible hand in hand. However, for the future, new rules for flexible production need to be developed together with workers to ensure that all parties are protected and that value is allocated fairly.

Other research has suggested that a lack of financial resources may hinder the development of innovative projects and new technologies in SMEs, while this is more difficult to happen in the case of Multi-National Enterprises (MNEs). In fact, being owned by a single person and facing several risks associated with their size, SMEs receive fewer investments compared to their counterparts, making them financially constrained. This condition, in turn, leads to substantial barriers to the upgrade of advanced production techniques and the adoption of integrated IT systems (Mittal et al., 2018). This latter element has also proven to be a potential crucial problem, as its implementation requires a perfect synchronization of different languages, components, and methods. Finally, it should be emphasised that innovative business models in the manufacturing sector will have to be supported by intellectual property rights and data security, otherwise concerns about the secure management of private information and data will increase.

A final obstacle, less mentioned in the literature and often underestimated by companies, is the role of organizational culture. Indeed, Industry 4.0 should be assessed first and foremost as a phenomenon of cultural change, which necessarily requires the acceptance of innovation. In some cases, people are not willing to change, either because they are afraid or because they are indifferent to it. Therefore, before introducing any change, it is essential to verify the presence of a culture of innovation and digital thinking (von Leipzig et al., 2017).

4.4. Two potential disruptive implications

In recent years, the higher level of technological development, stemming from the emergence and spread of Industry 4.0, has caused academia and policy to shift their attention towards some associated industry phenomena. Among the universe of possibilities, the interest has mainly been captured by reshoring on the one hand and sustainability on the other. Indeed, they both represent companies' strategic decisions and may be impacted by the selected technological approach. However, while the former has been widely studied and debated especially in the last few years, the evidence supporting the latter is still limited. Therefore, a stronger analysis will be provided for reshoring, whereas sustainability will be presented in a limited way, as a critical but still emerging phenomenon.

To begin with, the growing trend towards global value chains (GVCs) has recently shaped a new manufacturing landscape, where products and services are increasingly becoming the combination of different components originating from a variety of countries. It is not uncommon to spot a company which is only doing the assembling phase in its home country, while the main activities are performed abroad, either by wholly owned subsidiaries or external suppliers. The final manufactured goods, generally referred to as "made in the world" products, come however at the price of very fragmented value chains, causing higher coordination efforts, quality issues, longer time-to-market, and reduced flexibility. Furthermore, since the key reason underlying the deployment of GVCs was related to lower average production costs, they were considered to be one of the main reasons for the decline in manufacturing employment both in the US and European countries.

The choice of reshoring or backshoring has been defined by (Kinkel, 2020) as "*the decision to relocate manufacturing activities back to the home country of the parent company*". Specifically, according to (Gray et al., 2013), there are four different options that may trigger this condition: in-house reshoring, when a company moves the activities performed in wholly owned offshore facilities back to wholly owned home-country subsidiaries; reshoring for outsourcing, when a firm relocates activities performed in wholly owned offshore facilities back to home-based suppliers; reshoring for insourcing, when a company shifts the production process from offshore suppliers to wholly owned subsidiaries in the home country; and outsourced reshoring, when a firm transfers the manufacturing of products and services from offshore to home-based suppliers (Figure 13). Therefore, reshoring "*encompasses relocations from either offshore wholly owned facilities or from offshore suppliers to either own home facilities or home suppliers*" (Ancarani et al., 2019).

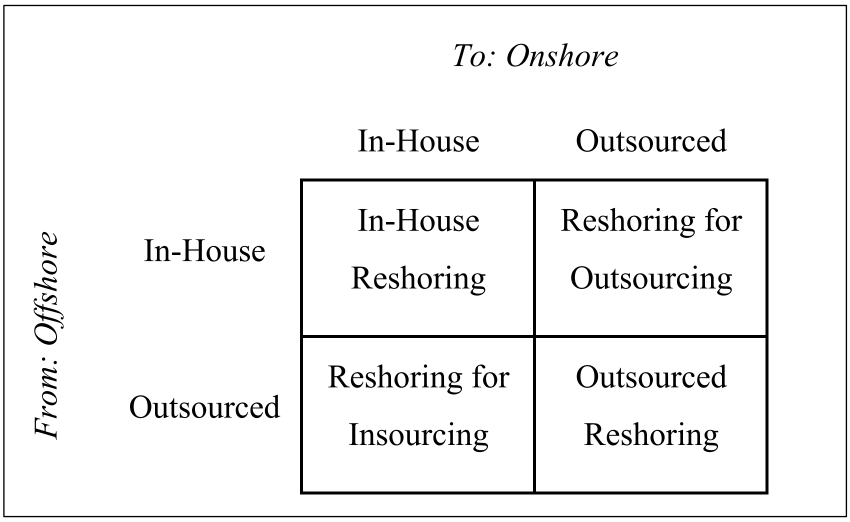

Figure 13: Reshoring options.
Source: Gray et al. (2013)

The last period has been marked by a growing interest in the relationship between the phenomenon just presented and technological development, also known as Industry 4.0. Indeed, the possibilities offered by these new advances range from reducing dependence on labour to improving quality and minimizing time and waste in production processes. An established literature has determined that behind location initiatives, as well as technological choices, there are decisions linked to the company's competitive priorities: cost, quality, flexibility, and delivery.

As a starting point, the perspective of Transaction Cost Economies (TCE) and Resource Based View (RBV) offer key insights for analysing the location decisions. According to TCE, offshoring is considered attractive especially in the case of low monitoring and coordination costs, thus for performing activities based on routine and modularity. In such cases, in fact, offshore locations characterized by low labour costs and economies of scale may represent an advantage, especially if transaction costs are not significantly impacted. On the other hand, RBV argues that the choice among which activities should be carried out offshore is based on the assessment of their related impact on the value added and the long-term capabilities of the organization. Therefore, it is crucial to maintain control over the critical phases of the value chain, while offshoring is more suitable for less value-adding steps.

Furthermore, as mentioned earlier, it is essential to determine how the advent of Industry 4.0 is expected to alter these location advantages depending on the specific competitive priority. First, the cost aspect implies that backshoring is convenient only if it is possible to retain economies of scale and competitive pricing; since Industry 4.0 technologies allow to substitute labour for capital by simultaneously increasing accuracy, the lower offshore labour costs may be more than counterbalanced by these effects. Second, quality is related to brand image and product performance focus; backshoring is successful only if new advances enable greater collaboration and information sharing, creating more value through the "Made in" and the closer control. Third, in terms of flexibility, variety and customization of products provided in a cost-effective way are crucial; the opportunity offered by Industry 4.0 with small-batch production at low costs and machine to machine communication can respond to these requests. Finally, as far as delivery is concerned, reliability and speed are critical factors; when backshoring, however, responsiveness increases due to higher proximity and better service offered to the customers, thus reducing the pressure on new technology investments.

In particular, results from the empirical analysis carried out by (Ancarani et al., 2019) suggest that reshoring in the sample of European companies covered in their study was mainly driven by two factors, namely high product performance (quality) and cost of rework and returns from customers (cost of non-conformance). In fact, the additional time, material and labour required by reworks and returns generate hidden costs, since they are generally not recorded in the firm's accounting system. If the production process is mainly performed by robots and machines, the number of defective products and the need for inspections will naturally decrease, thus resulting in higher productivity. Similarly, when quality control is required along the entire value chain, the adoption of automated processes improves accuracy and precision standards, in some cases even overcoming the need for specialized expertise. Finally, after discovering that backshoring increases with size, (Dachs et al., 2019) found that flexibility was another crucial element driving the phenomenon, as more than half of the analysed companies reported the need to stay as close as possible to their consumers. Indeed, as it emerges from the calculated export intensity, the majority of sales is realized in the companies' home country.

On the other hand, a common issue that characterized every industrial revolution was the need to produce more goods with the same or even fewer natural resources. The main objective was to satisfy the growing demand while at the same time preserving and possibly limiting negative outcomes from the community. Indeed, sustainability is a broad concept comprising not only the environment, but also the economic and social development, which together constitute the so-called "triple bottom line". Environmental sustainability is mainly based on the preservation of the environment's equilibrium, the balance between consumption and replenishment, and the integrity of the ecological system. Differently, economic sustainability concerns the ability to generate stable, long-term growth by efficiently combining resources, enhancing the specificity of products, and generating value added. Finally, social sustainability regards the process of ensuring equal human conditions, but also healthy and habitable communities where discrimination is excluded and everyone has access to basic services.

The advent of Industry 4.0, in the form of interconnected devices and intelligent systems that sometimes make decisions with limited human intervention, may have a contradictory impact on the triple bottom line. In fact, on the one hand, new technologies can help reduce waste by making processes more efficient and increasing the productivity of the resources involved. However, on the opposite side, the increased rate of production allowed by automation can generate higher resource consumption as well as pollution concerns (Ghobakhloo, 2020). Two steps appear very relevant in this context. First, projecting new machines that can manage energy utilization and reduce overall consumption, with positive indirect effects on the social community, such as better air quality and fewer greenhouse gas emissions. Second, supporting the transition towards renewable energy.

For this latter element, however, most European countries have demonstrated to be lagging behind. The conflict between Russia and Ukraine, with the consequent reduction of gas supplies to the EU, has made the problems of energy dependence very relevant, forcing European leaders to pay a huge price for the same supply and simultaneously sign contracts with alternative, although less reliable and less "green," gas suppliers. At the time of writing, speculation has pushed gas prices to an unprecedented level, companies are struggling to keep production going on, and citizens are worried about the possibility of not having warm in their houses during the winter season. Everything is amplified by a rapidly growing inflation at a level above 9%. In a recent announcement, Christine Lagarde, president of the European Central Bank (ECB), claimed that about one third of the current inflation is due to the increased price of energy. Specifically, compared to the first half of the previous year, gas and electricity prices have risen respectively by more than 650% and 450%. An answer has also come from the president of the European Commission (EC), Ursula von der Leyen, who claimed the need to be prepared for a possible full disruption of Russian gas. In this scenario, she argued it is essential for countries not only to reduce energy consumption and save it to the storage, but also to accelerate the green transition: "*with the RePowerEU, we will invest up to €300 billion to accelerate the green switch*". Nonetheless, despite all these attempts to mitigate the impact on the economic system, the economy is expected to contract next year, while a recovery is expected from 2024 onwards. It is therefore difficult, at least in the short term, to imagine that companies will be proactive in terms of investing in new technologies, especially if they also face energy constraints.

Finally, as underlined at the end of the second chapter, social considerations should not be ignored. Indeed, the digital transformation is expected to have a disruptive impact on the labour market, with many lower-skilled jobs being replaced by the emergence of labour-saving technologies. At the same time, innumerable job opportunities will emerge in the fields of automation engineering, control system, and machine learning, thus raising concerns about the unequal distribution of wealth among social classes. Educational policy, together with long-life learning, will be key to solving these crucial issues.

The final section of this work will attempt to answer the second research question, namely to what extent the Italian market has been impacted by the advent of the Fourth Industrial Revolution. In particular, starting from the variables presented earlier in this chapter, some preliminary conclusions will be drawn on the relationship between Industry 4.0, labour market, and labour share of income.

5. THE EFFECTS OF INDUSTRY 4.0 ON THE ITALIAN MARKET

Having analysed the current situation in terms of I4.0 adoption in the main European countries, including the key driving and limiting factors, it is now the moment to examine how these hypotheses translate into reality in the Italian context. To do so, it has been necessary to look for a database containing information potentially relevant for the scope of the present work, namely the relationship between Industry 4.0 and the three crucial variables hitherto investigated: productivity, employment, and wages.

5.1. The database

After an accurate evaluation of the possible databases that could serve the purpose of this work, the Bank of Italy's "Survey of Industrial and Service Firms" was selected. Indeed, not only has this survey approximately 5000 firms in the panel, but it also includes very recent questions about Industry 4.0 and its related effects. Specifically, companies were asked questions on automation technologies between 2015 and 2021; in odd years, they provide information about the usage of new technologies which may replace labour inputs in several tasks. Firms provide an answer on the current state of their technological level, a binary response on the effective use of each technology, and the share of total investment destined to advanced technologies. The survey includes both physical (Industrial Robotics and 3D Printing) and digital technologies (Cloud Computing, Artificial Intelligence, Big Data, and the Internet of Things). However, two limitations should be noted. The first, less notable, is the fact that most data on technology usage in 2021 are not already available, so in some cases the analysis will not be extremely up to date. The second, much more relevant, is related to the size of the covered firms. Looking at the size distribution (Figure 14), it can be noted that only firms with at least 20 employees are included in the study, thus representing an important limitation.

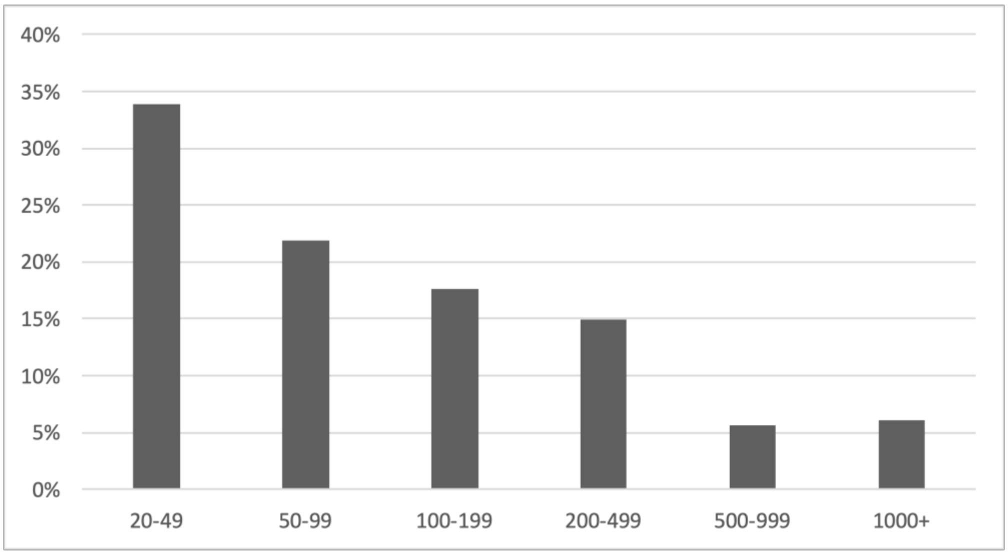

Figure 14: Average company size distribution of Bank of Italy's panel data between 2016-2021.
Source: Author's elaboration on the Survey of Industrial and Service Firms, Bank of Italy

Indeed, according to Istat, in 2019 more than 98% of all Italian companies employed up to 19 employees. Moreover, the value added by firms with less than 20 employees was more than half of the value generated by companies with at least 20 employees. Finally, concerning employment, firms in the range of 0-19 employees have a higher number of workers compared to those in the range of 20-250+ (Table 2).Table 2: Main enterprises economic indicators by class size

Table 2: Main enterprises economic indicators by class size in Italy in 2019.
Source: Author's elaboration on ISTAT database

Year	2019		
Size class	0-19	20-250	250+
Number of enterprises	4.126.599	78.323	4.057
Value added (thousands of euros)	300.053.739	233.875.954	291.647.330
Persons employed	9.070.677	3.881.621	3.929.652

Despite this important limitation, it is evident that this dataset represents one of the best sources that can be used, both for its wideness and reliability. Indeed, not only it is excellent to examine the proportion of firms that automate, but also to understand how it changed over time, and which effects these choices had. As a general overview, it is due noting that the average firm is 38 years old, has 380 employees, and a turnover of €150 million.

5.2. Automation in Italian companies

As a starting point for this analysis, it might be interesting to assess the general level of technological development in companies prior to the advent of the Fourth Industrial Revolution. Fortuitously, in 2014, just before the introduction of the concept of Industry 4.0 and all the policies and measures associated with it, the Bank of Italy administered a questionnaire to firms to understand their opinion on the technology they were using. The answers, which ranged on a scale from 1 to 4, demonstrated that Italian companies were rather up to date with respect to innovations, with more than 50% of the interviewed companies referring to a level of technology equivalent to the most advanced, and a further 35% describing it as medium-high (Figure 15).

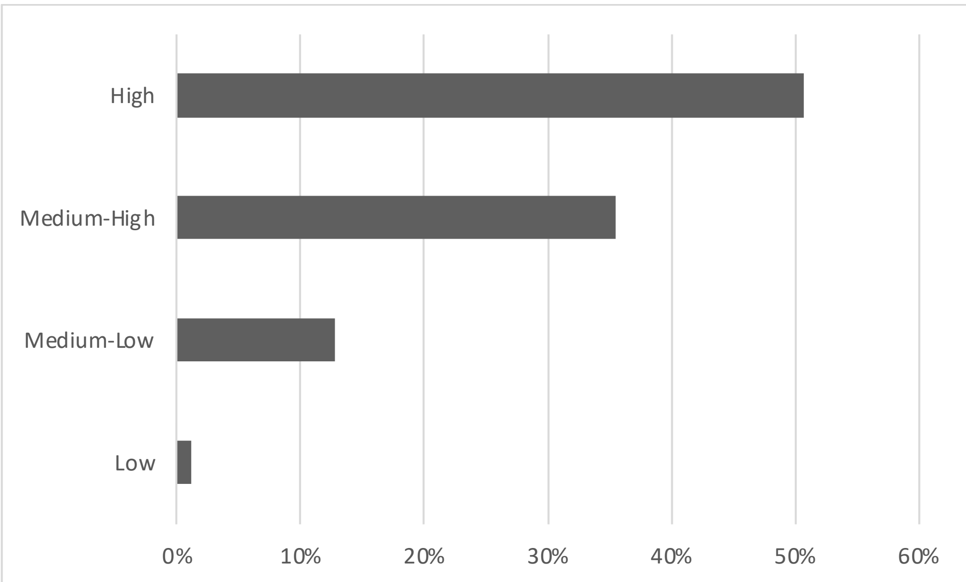

Figure 15: Opinions of Italian companies on technology possessed in 2014.
Source: Author's elaboration on the Survey of Industrial and Service Firms, Bank of Italy

Companies with a lower level of technological development were also asked about the main reasons driving their reduced investments. As shown in (Figure 16), the first three explanations consisted of a lack of financial resources, a production scale too small to justify the investment and excessive internal reorganisation costs.

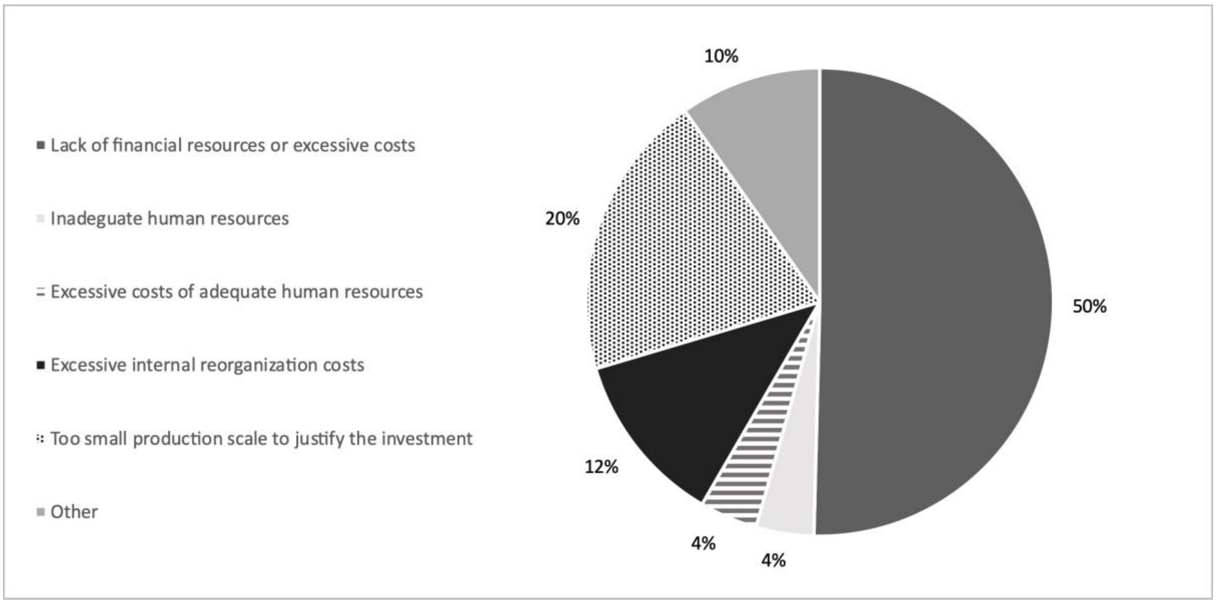

Figure 16: Main reasons for the low level of technology investment in Italian companies in 2014. Source: Author's elaboration on the Survey of Industrial and Service Firms, Bank of Italy

In 2015, questions about automation adoption were answered by about 3400 companies, a value that grew to more than 3800 in 2016 but then decreased to a little bit more than 2000 in 2019. As it can be seen from Figure 17, the most used advanced technologies in the first year of the study were Internet and Cloud (with a value of 73%, which was however largely due to the adoption of Internet, given the much lower value of 16% registered by the category in the following covered year) and Internet of Things (19%), while Advanced Robotics, AI and Big Data, and 3D Printing ranged in a value between 14% and 11%. While 2017 showed in most cases the same or little lower numbers with respect to the above-described ones, something different happened in 2019. Indeed, except for 3D Printing, which decreased its value by about 1%, all the other technologies showed increases, from a small 1% of Advanced Robots, to a medium 3% of AI and Big Data[17], and a huge 9% of Cloud.

[17] It is due noting that due to different ways to measure this variable by the Bank of Italy's survey, further computations for this value have necessarily been done. Indeed, while it was collected a unified value for AI and Big Data in 2015, it started being split from 2017 onwards. Therefore, to keep consistency across data and descriptive statistics, it was computed the sum of their value without the intersection, thus avoiding the double counting of some observations.

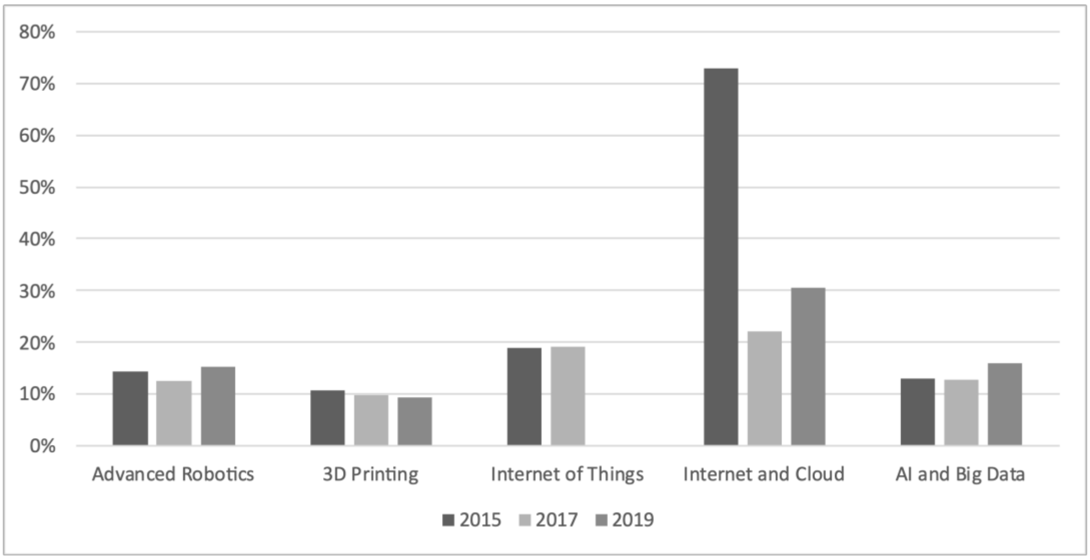

Figure 17: Industry 4.0 technologies adoption in Italy between 2015 and 2019.
Note: the proportion of firms adopting Internet of Things in 2019 was not available in the dataset.
Source: Survey of Industrial and Service Firms, Bank of Italy

It is then instructive to compare the above proportions with the amount of people employed by the adopting firms. It emerged that companies adopting any of these advanced technologies showed important rises in their employment (Figure 18). Specifically, by computing the Compound Annual Growth Rate (CAGR), it was found that the highest growths in people employed were registered by firms using Advanced Robotics and Cloud, with a value of respectively 26% and 24%. Less evident but still valuable results were achieved by AI and Big Data (15%) and 3D Printing (12%). However, more interestingly, it can be noted that not always a higher adoption rate is related to a higher employment level: although decreasing in adoption proportion, 3D Printing showed a growth in employment at a similar pace of other technologies.

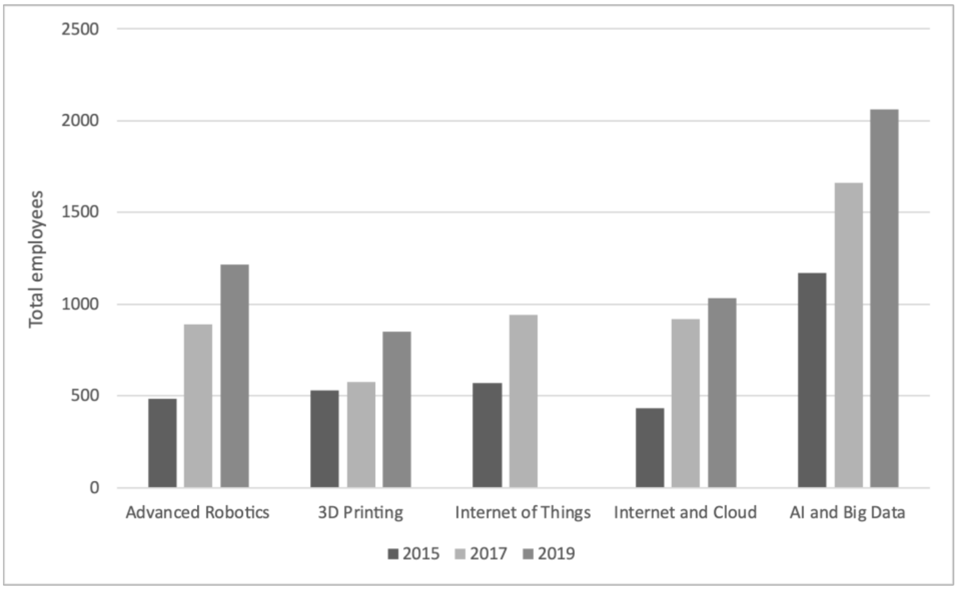

Figure 18: Employment by technology adopted in Italy between 2015 and 2019.
Note: the employment of firms adopting Internet of Things in 2019 was not available in the dataset.
Source: Survey of Industrial and Service Firms, Bank of Italy

A final important descriptive statistic is the correlation between the adoption of different technologies. It might be expected that the usage of any I4.0 technology will probably favour the adoption of other related innovations. This was effectively confirmed by data, but with different intensities depending on the type of technology considered. Indeed, considering 2017 and 2019 (when Cloud was split up from Internet, and AI and Big Data were computed separately), it emerged a clear distinction between digital and physical technologies. While the former generally showed the highest correlation values when combined among each other, the latter had a more unstable pattern. Indeed, on the one hand 3D printing confirmed this trend, on the other hand Advanced Robotics exhibited quite good results independently from the type of technology it was combined to (Table 3)

Table 3: Technologies' correlations in Italian companies in 2017 and 2019.

Source: Author's elaboration on the Survey of Industrial and Service Firms, Bank of Italy

2017	Advanced Robotics	3D Printing	Internet of Things	Cloud	Artificial Intelligence	Big Data
Advanced Robotics	1					
3D Printing	0,290	1				
Internet of Things	0,296	0,260	1			
Cloud	0,165	0,181	0,315	1		
Artificial Intelligence	0,327	0,155	0,325	0,246	1	
Big Data	0,221	0,189	0,410	0,367	0,367	1

2019	Advanced Robotics	3D Printing	Cloud	Artificial Intelligence	Big Data
Advanced Robotics	1				
3D Printing	0,290	1			
Cloud	0,135	0,175	1		
Artificial Intelligence	0,342	0,217	0,236	1	
Big Data	0,229	0,156	0,433	0,375	1

5.3. Features of Industry 4.0 adopters

Having presented an overview of the adoption of Industry 4.0 in the Italian market, it is crucial determining what the main drivers of these results have been. Recalling the analysis carried out in the previous chapter, this paragraph will investigate the effects of three dimensions, namely public policy implementation, international presence, and strategic innovations. While descriptive results will be provided for public policies, a regression analysis will be conducted for the other two aspects. In addition, this regression will also comprise firm size, both for the characteristics of the firms included in the database and for the possible correlation with the adoption of new technological developments. As partial evidence of this, by processing the aforementioned survey on the opinion about the possessed technology, firms with a larger number of employees seem to classify their technological level in a better way.

The first element to be tested was therefore the relationship between firm size and relative expenditure on advanced technology. The regression has been set as the level of investment in new technologies relative to the logarithm of employment, controlling for age, region, and sector:

$$Technology\ investment = \beta_0 + \beta_1 \ln(Employment) + \beta_2 Age + \beta_3 Region + \beta_4 Sector + \varepsilon_i$$

Results demonstrate that over the period 2017-2021, each percentage change in the number of employees in a company resulted in an increase in technology expenditure[18], thus signalling a positive effect of firm size (Table 4). While these values were always found to be statistically significant across all years analysed, on the other hand, no or minimum effect was found between new digital investments and the age of the company. In contrast, concerning region and sector, two interesting elements emerged. The first regarded the location of the business: in 2017, belonging to the northern area of the country had a positive effect on investments made in the field of advanced technologies, whereas this evidence seems to have disappeared in recent years. On the one hand, a possible explanation for this trend may be related to public policies that have favoured digital investments regardless of the geographical area. On the other hand, companies may have noticed that to remain competitive in such a complex economic environment, it was necessary to keep up with new advances. This, in turn, may have naturally resulted in an exit from the market of companies located in the south and less prepared for the advent of the Fourth Industrial Revolution. The second finding that emerged concerned cross-sectoral differences: in all the years analysed, three sectors showed much lower spending in terms of new technological investments, namely extractive industries, wholesale and retail trade, and hotels and restaurants.

[18] In this case, it was not possible to assess the magnitude of the effect, as the variable concerning the share of investment in new technologies was coded with values between 1 and 5.

Table 4: Share of Italian companies' investments in new technologies by size, age, region, and sector between 2016 and 2021.
Source: Author's elaboration on the Survey of Industrial and Service Firms, Bank of Italy

	Share of investment in advanced technologies		
Year	**2017**	**2019**	**2021**
Size	0.195***	0.193***	0.161***
	(0.017)	(0.024)	(0.022)
Age	0.0001	0.002	0.003*
	(0.0008)	(0.001)	(0.001)
Region	-0.114***	-0.023	-0.020
	(0.018)	(0.029)	(0.023)
Sector	Yes	Yes	Yes
Multicollinearity test	✓	✓	✓
T test	✓	✓	✓
Breusch-Pagan test	✓	✓	✓
Durbin-Watson test	✓	✓	✓
N	3724	1965	3297

*Note: Estimates are significant at levels of 0.1%: ***, 1%: **, 5%: **

Having confirmed that size is fundamental to the technological development of a company, it is time to define how much the other three factors mentioned above may have played a role in the process. The first element needing further investigation is the effectiveness of the policy adopted by the government, which usually represents the confirmation step before the diffusion of a new paradigm. As mentioned earlier, the Italian government has mainly supported the technological development through fiscal measures, such as the hyper and super depreciations schemes and the simplified access to financing (Nuova Sabatini). The question is how crucial the role of these incentives has been in encouraging the adoption of new physical and digital innovations. Data show that the most successful measure was super depreciation, while Nuova Sabatini represented the least used (Figure 19).

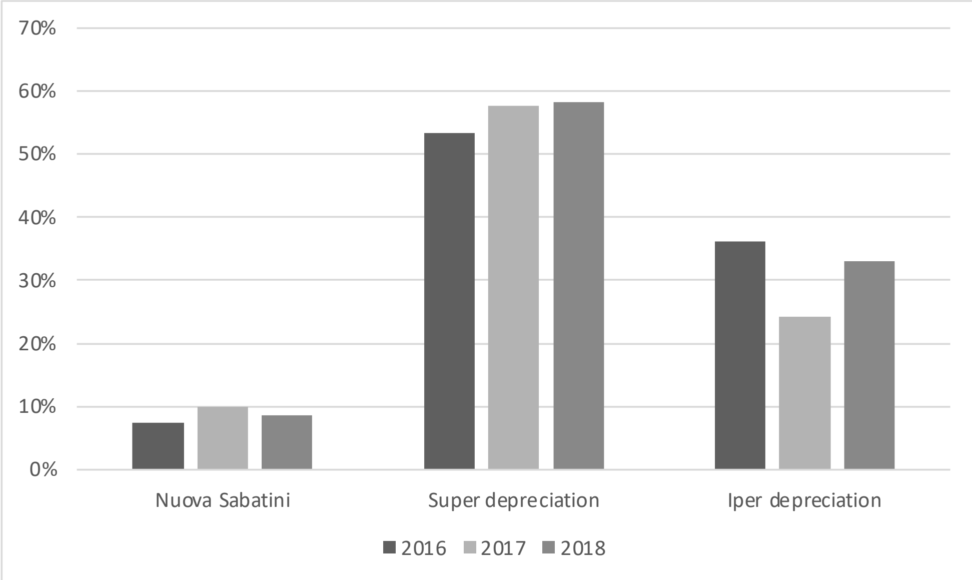

Figure 19: Utilization rate of the main fiscal measures proposed by the Italian government between 2016 and 2018. Source: Author's elaboration on the Survey of Industrial and Service Firms, Bank of Italy

However, this apparent much more frequent use of new depreciation schemes compared to Nuova Sabatini is distorted. In fact, in 2015, before the introduction of all the measures, companies were asked to indicate the amount of investment that would be made regardless of the depreciation incentives. This value turned out to be about 80% of the total expenditure. Therefore, the net effect of new depreciation schemes should be calculated as around 20% of the recorded values, resulting between 8% and 12%. This adjustment allows the net usage of all measures supported by the Italian government to be estimated at around 10%. Finally, about one third of the companies that did not use Nuova Sabatini were asked about the main reasons underlying this choice. From Figure 20 it can be observed that the main motivations were twofold: on the one hand the measure was not considered the desired one (64%), on the other hand the conditions for accessing it were lacking (24%).

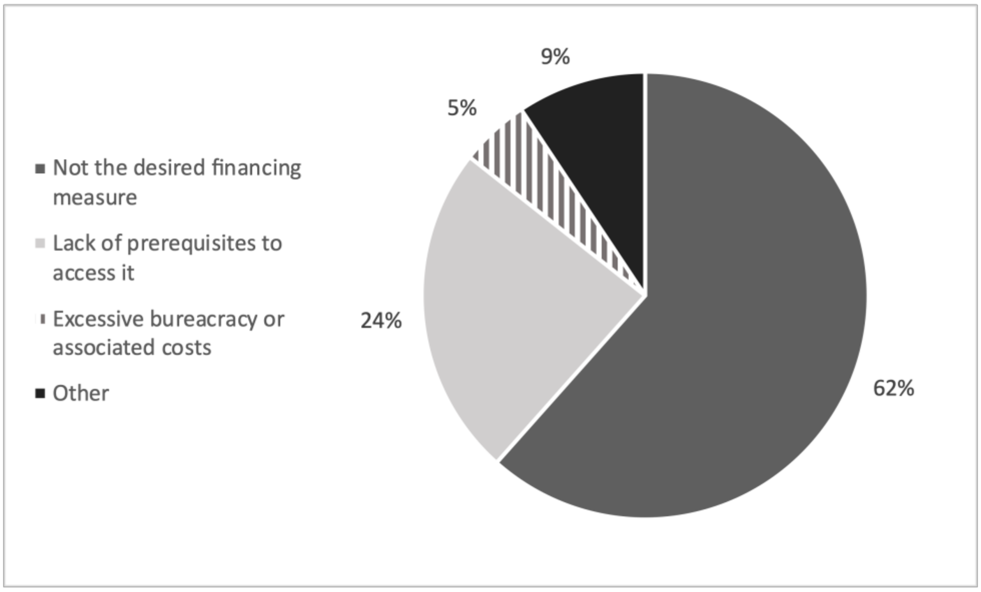

Figure 20: Main reasons why Nuova Sabatini was not used by Italian companies in 2015.
Source: Author's elaboration on the Survey of Industrial and Service Firms, Bank of Italy

As for the relevance of international presence and strategic innovations, the regression model has been set up in the simplest possible way. First, it has been defined a common dependent variable, namely the use of at least one I4.0 technology. Second, both phenomena have been included in the regression as explanatory variables. As far as international presence is concerned, the approach was rather simple. In fact, the nationality of the parent company was used as a proxy for the level of globalization, although there may also exist multinational firms for which the parent company is located in Italy. In contrast, with regard to strategic innovations, some issues have arisen due to limited data availability. Indeed, the most recent data dated back to 2014 and referred only to the introduction of innovations from a business model perspective or in terms of products and services. Therefore, the proxy for this variable has been set as the choice or not to implement one of the above-mentioned innovations in that specific year. Finally, due to the relevance showed before, company size has been included as a third explanatory variable:

$$I4.0\ Adoption = \beta_0 + d_1 Nationality + d_2 BM\ Innovation + d_3 Product\ Innovation + \beta_1 \ln(Employment) + \beta_2 Age + \beta_3 Region + \beta_4 Sector + \varepsilon_i$$

The results were very interesting: controlling for age, region, and sector, the most significant factor was again represented by firm size. In particular, for each percentage change in the number of employees of a company, the adoption of Industry 4.0 increased between 5.4% and 11.1%. However, the mere fact that the company had an international presence showed no correlation with the likelihood of technology adoption. This evidence might be counterintuitive, but it should be noted that the proxy used for globalization was very approximate. Moreover, the proxy could be distorted by firms that, despite actually operating only in Italy, decide to locate their headquarters in another country to benefit from tax incentives or other fiscal advantages. If there had been a dummy variable indicating the presence of more than two subsidiaries abroad, the model could have provided more accurate estimates. On the other hand, the introduction of advanced technologies was found to be positively associated with the development of new business models, products, or services. Specifically, the probability of adopting any I4.0 technology in 2017 and 2019 was between 11.1% and 15.4% higher for companies that implemented a strategic innovation in 2014 (Table 5). It is fair, indeed, to assume that innovations take some time before effectively translating into new technologies adoption. This, in turn, is more common in flexible companies that are ready to change their business models and adapt their offerings to better serve their consumers. Finally, as in the previous model, it can be noted that the role of company age was never found to be statistically significant. This result may hide an important implication, namely that younger companies are not always the most active in adopting innovations and established firms are not the only ones able to invest. In fact, sometimes other underestimated factors, such as organizational culture, can play a very crucial role: the climate within an organization, as well as the type of employees working there, can really suggest the most appropriate path for the future development and determine whether the company will prosper or suffer in the years to come.

Table 5: Level of Italian companies' technology adoption by international presence, business model innovation, product and service innovation, size, age, region and sector between 2015 and 2019.
Source: Author's elaboration on the Survey of Industrial and Service Firms, Bank of Italy

	I4.0 technology adoption		
Year	**2015**	**2017**	**2019**
Nationality	0.044	0.048	-0.034
	(0.042)	(0.046)	(0.062)
BM.inn	0.041	0.125***	0.111**
	(0.026)	(0.028)	(0.040)
Prod/Serv.inn	0.007	0.154***	0.143**
	(0.028)	(0.030)	(0.043)
Size	0.054***	0.102***	0.111***
	(0.011)	(0.012)	(0.016)
Age	-0.0001	0.0004	-0.0004
	(0.0005)	(0.0006)	(0.0009)
Region	0.017	-0.036*	-0.037
	(0.011)	(0.013)	(0.019)
Sector	Yes	Yes	Yes
Multicollinearity test	✓	✓	✓
T test	✓	✓	✓
Breusch-Pagan test	✓	✓	✓
Durbin-Watson test	✓	✓	✓
N	1219	1137	613

*Note: Estimates are significant at levels of 0.1%: ***, 1%: **, 5%: **

Lastly, a study was conducted on the most recent applications of Industry 4.0, namely backshoring and sustainability. Regarding backshoring, given the presence in the database of very recent data, a linear regression analysis has been set up. Specifically, the dependent variable has been expressed as the choice to implement one of the investigated reshoring options, namely the replacement of foreign suppliers with domestic ones or the closure of an international subsidiary. The explanatory variable has been defined as the adoption of at least one I4.0 technology and controls for age, size, region, and sector were included as usual. However, despite the positive sign of the correlation, little or no significance was found. The same results were observed for sustainability, where, however, the variable for which data were collected did not fully investigate the phenomenon. Indeed, the proxy closest to the phenomenon was found to be the decision of whether or not to maintain an accounting of direct or indirect CO_2 emissions, far away from the more complex topic of the triple bottom line. The explanatory variable was instead kept constant. There may be two reasons for this lack of evidence. The first could be related to the scarcity of data, especially regarding sustainability. The second could be associated to the peculiar period we have been going through. Indeed, especially for reshoring, the Covid-19 global pandemic, more than automation, may have favoured the decision of firms to relocate closer to their home countries.

5.4. Effects on the Italian economic system

After investigating the level of I4.0 automation in the Italian market and the characteristics representing the adopting companies, it is worth concluding this chapter with an analysis of the impact that technological development had on the Italian economic system, and specifically on the three main variables explored throughout the present work: productivity, employment, and wages.

As previously done, it is interesting to start directly from the opinion of companies on the effects generated by the Fourth Industrial Revolution. Unfortunately, this topic has been addressed by only two surveys, whose data were collected in 2021. In addition, the questions do not directly deal with the three elements mentioned above, but with other related issues. The first is closely linked to occupation, since it covers the opinion of firms with respect to the employment of workers performing manual and/or routine activities. The second is much more indirect, as it refers to the impact of Industry 4.0 enabling technologies on all the other production costs and may therefore provide an indication of the incentive to substitute workers for machines. The results were consistent with findings in the literature: around 90% of the interviewed companies reported a medium to high reduction both in the use of routine workers and in other production costs (Figure 21). As suggested by several scholars cited earlier, these effects may be interrelated: Industry 4.0 may promote the implementation of automation at the expense of low-skilled jobs.

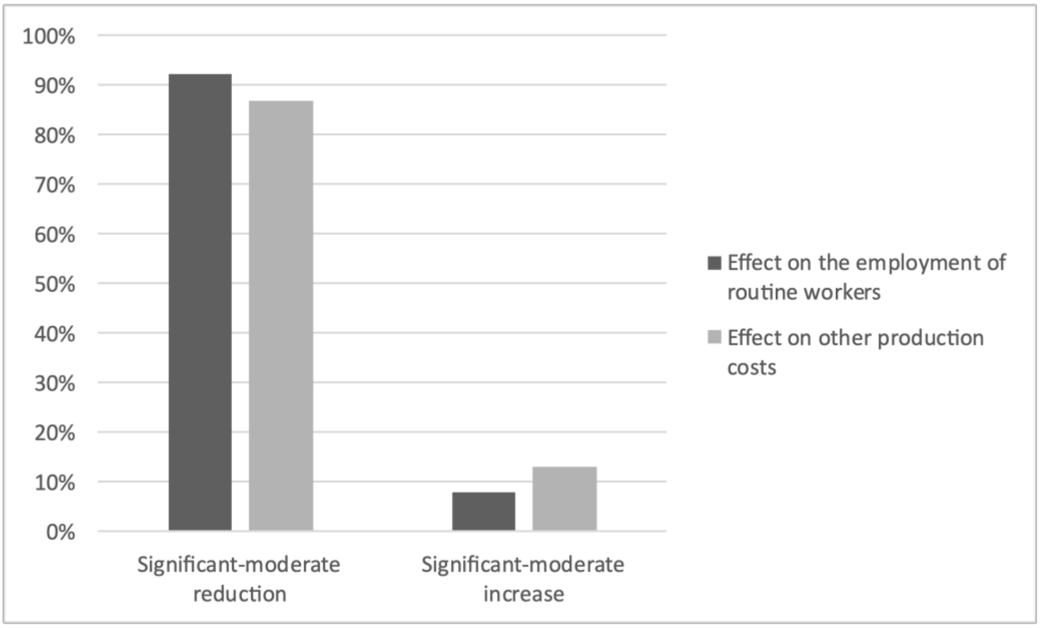

Figure 21: Opinions of Italian companies on the impact of I4.0 technologies on workers and production costs in 2021. Source: Author's elaboration on the Survey of Industrial and Service Firms, Bank of Italy

The analysis that follows will be based on the study of the impact of new technologies on the aforementioned labour market variables, first from a short-term perspective, then from a longer-term one. The main objective of the first study was to identify the effect of the implementation of any Industry 4.0 technology on the annual variation of the variables under research. On the other hand, the aim of the second study was to clarify whether, over a longer period, the companies that have adopted new technologies have outperformed the others.

As far as the short-term is concerned, the dependent variable has been defined as the annual variation between its value in t and that in t+1. In the case of labour productivity, given the absence of a direct measure in the database, the value has been derived in an indirect way, namely calculating the ratio of total turnover to actual hours worked in the respective years. Completing the linear regression, technology adoption has been defined as a dummy explanatory variable, with controls for age, size, region, and sector included as usual:

$$Labour\ Productivity\ Change = \beta_0 + d_1 I4.0\ Adoption + \beta_1 \ln(Employment) + \beta_2 Age + \beta_3 Region + \beta_4 Sector + \varepsilon_i$$

The overall effect of new technologies on the change in labour productivity in the following year was not found to be statistically significant. However, when considering the level of labour productivity instead of its annual change, it emerged how the adopting companies had an advantage over the others. Indeed, as can be seen in Table 6, the adoption of any Industry 4.0

technology resulted in a productivity level between 11.1% and 16% higher, especially in companies located in northern Italy.

Table 6: Labour productivity level in Italian companies by technology adoption, size, and age between 2015 and 2019. Source: Author's elaboration on the Survey of Industrial and Service Firms, Bank of Italy

	Labour Productivity		
Year	**2015**	**2017**	**2019**
I4.0 adoption	0.111***	0.160***	0.149***
	(0.033)	(0.028)	(0.038)
Size	0.045***	0.020	0.015
	(0.012)	(0.011)	(0.015)
Age	-0.001	-0.0007	-0.001
	(0.0006)	(0.0005)	(0.0008)
Region	-0.108***	-0.132***	-0.172***
	(0.013)	(0.012)	(0.018)
Sector	Yes	Yes	Yes
Multicollinearity test	✓	✓	✓
T test	✓	✓	✓
Breusch-Pagan test	✓	✓	✓
Durbin-Watson test	✓	✓	✓
N	3341	3785	2062

*Note: Estimates are significant at levels of 0.1%: ***, 1%: **, 5%: **

Given the uncertainty and high variability of the evidence emerging from the literature, employment and wages have represented the most interesting topics in the present analysis. For their study, the approach used has been the same as the one just seen, namely the estimation of a linear regression model. As far as employment is concerned, the dependent variable has been computed as the rate of change of firm size, while the explanatory variable has been kept as the use of at least one technology in each period:

$$Employment\ change = \beta_0 + d_1 I4.0\ Adoption + \beta_1 Age + \beta_2 Region + \beta_3 Sector + \varepsilon_i$$

Controlling for age, region, and sector, results showed a positive relationship between the technology adoption of a given firm and the employment change in the following year. This association seems to have increased over time and to be stronger for older firms (Table 7). However, it is worth mentioning that since it was also found that company size played a crucial role in favouring the implementation of the most advanced technologies, causation could go both ways: the implementation of new I4.0 technologies may have increased the number of employees in a firm, as well as an increase in employment may have resulted in a higher level of technology adoption. Further and more complex statistical analyses will therefore be necessary to assess the actual direction of the phenomenon.

Table 7: Employment change in Italian companies by technology, age, region, and sector between 2015 and 2019. Source: Author's elaboration on the Survey of Industrial and Service Firms, Bank of Italy

	Employment change		
Year	2015	2017	2019
I4.0 adoption	0.006	0.010**	0.013**
	(0.004)	(0.003)	(0.004)
Age	0.0002*	0.0002*	0.0003***
	(0.0001)	(0.0001)	(0.0001)
Region	-0.002	-0.001	-0.007***
	(0.001)	(0.001)	(0.002)
Sector	Yes	Yes	Yes
Multicollinearity test	✓	✓	✓
T test	✓	✓	✓
Breusch-Pagan test	✓	✓	✓
Durbin-Watson test	✓	✓	✓
N	3341	3785	2062

*Note: Estimates are significant at levels of 0.1%: ***, 1%: **, 5%: **

Finally, as far as wages are concerned, the dependent variable of the regression has been computed as the variation of gross annual salary in each analysed year, while the explanatory variable has been defined again as the adoption of at least one I4.0 technology:

$$Gross\ Salary\ Change = \beta_0 + d_1 I4.0\ Adoption + \beta_1 \ln(Employment) + \beta_2 Age + \beta_3 Region + \beta_4 Sector + \varepsilon_i$$

The results were very similar to those observed for labour productivity: no evidence in the annual variation, statistical significance when considering the level of gross salary as dependent variable. Specifically, in 2017 and 2019, wages paid by adopting companies were found to be between 5.3% and 8.4% higher, with young age and location in the northern region playing an important role (Table 8).

Table 8: Level of wages paid by Italian companies by technology, age, and region between 2015 and 2019. Source: Author's elaboration on the Survey of Industrial and Service Firms, Bank of Italy

	Wages		
Year	**2015**	**2017**	**2019**
I4.0 adoption	0.024	0.053***	0.084***
	(0.013)	(0.011)	(0.015)
Size	0.018***	0.010	-0.003
	(0.005)	(0.005)	(0.006)
Age	-0.001***	-0.001***	-0.001***
	(0.0002)	(0.0002)	(0.0003)
Region	-0.071***	-0.071***	-0.081***
	(0.005)	(0.005)	(0.007)
Sector	Yes	Yes	Yes
Multicollinearity test	✓	✓	✓
T test	✓	✓	✓
Breusch-Pagan test	✓	✓	✓
Durbin-Watson test	✓	✓	✓
N	2520	3112	1733

*Note: Estimates are significant at levels of 0.1%: ***, 1%: **, 5%: **

Two conclusions can be drawn. On the one hand, the higher level of compensation reserved for those working in the field of advanced technologies may determine a shift of workers towards these types of jobs, which currently can only count on limited resources. On the other hand, considering Industry 4.0 alone in the period 2015-2019, it seems that the adoption of new technologies did not produce immediate effects on the change in labour productivity and level of compensation.

The overall impact should therefore be assessed by considering a longer time period and evaluating the behaviour of the main economic variables in this perspective. To do this, it was first decided to create a new data frame in which to insert a new variable indicating the use of at least one I4.0 technology in one of the years under study. This variable has been codified as a dummy, so the level of technological depth was not investigated in this case. Nonetheless, this treatment made it possible to distinguish between adopters and non-adopters of Industry 4.0. At this point, for each category, the average values of the variables under study were calculated in both 2015 and 2019, allowing the associated CAGR to be computed. As can be seen in Figure 22, adopting companies showed a higher growth rate in labour productivity and wages. Furthermore, since the growth rate of wages was higher compared to that of labour productivity, recalling the analysis presented in Chapter 3, an increase in the labour income share should be expected.

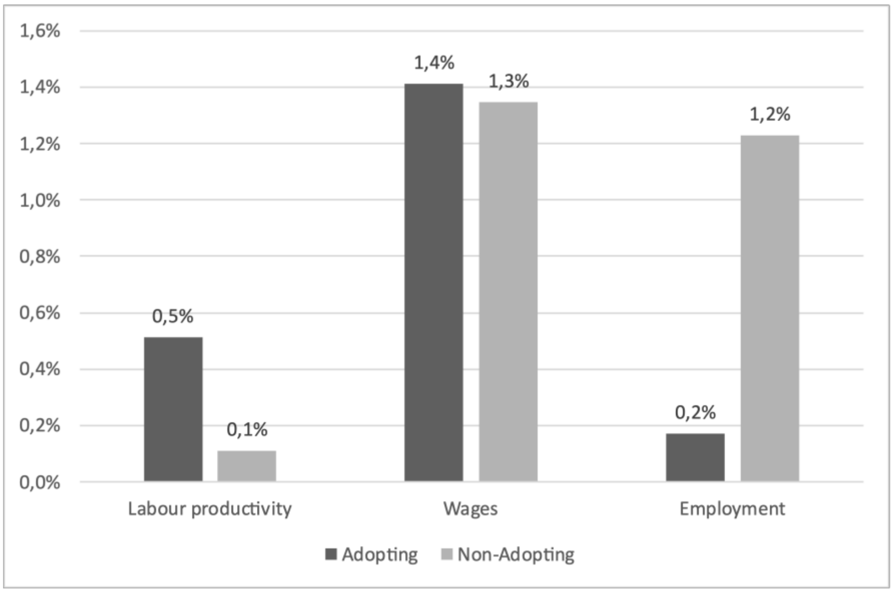

Figure 22: Growth rates of labour productivity, wages, and employment in adopting and non-adopting companies between 2015 and 2019.
Source: Author's elaboration on the Survey of Industrial and Service Firms, Bank of Italy

However, it is also important to remember that non-adopting companies should be treated as a control group and the analysis should be performed on differentials. It is therefore possible to state that adopting companies experienced a 0.4% higher growth rate in labour productivity than non-adopting ones, while for wages this effect was reduced to 0.1%. Recalling the theory once again, this should translate into a decrease in the labour income share. In this perspective, the growth recorded in the employment of adopting companies, amounting to about 0.2%, should be read as a decrease of about 1%. However, when testing the causal relationship existing between the adoption of Industry 4.0 and the CAGR of the above-mentioned variables, no statistical significance was found. Therefore, it is possible to conclude that Industry 4.0 adopters are responsible for the recent decline in the Italian labour share of income, but this phenomenon is not driven by the implementation of the latest technological developments.

CONCLUSIONS

With the aim of understanding the relationship between new Industry 4.0 technologies and human labour, several interesting results have been collected throughout this work. Indeed, the qualitative analysis, supported by reliable data, has made it possible to offer a comprehensive overview of this phenomenon, the effects of which, however, will only be effectively assessed in several years' time.

Elaborating from the AMECO database, it was first discovered that, although remaining quite constant during the previous century, the labour share of income of selected OECD countries has steadily decreased in the last 30 years. The case of Italy turned out to be particularly dramatic, as the value of the variable dropped from 77% in 1960 to 60% in 2020. According to the economic theory, a reduction in the labour share generally reflects a higher growth in labour productivity with respect to average labour compensation. Therefore, the main causes for this labour productivity growth were analysed, with ICT investment resulting the most decisive factor. Indeed, although at a first glance the trend of ICT expenditure relative to GDP seemed to be declining, further decomposing its constituents, it was found that the category of computer software and databases (more in line with the latest technological advances) followed a completely different path. This result was further reinforced by possible measurement underestimations and evidence of an increase in volumes over the same period.

Shifting the focus on Industry 4.0, a general overview of its development at the European level was provided. As a starting point, a digitization index based on the adoption rates of new technologies in the main European countries was created, and it almost coincided with the official Digital Intensity Index published by Eurostat. Indeed, they both highlighted the technological prominence of Germany and the poor performance of France, with Italy very close to the latter. Subsequently, a comparison of public policies was made, revealing a quite harmonised landscape, with measures generally requiring a combination of public and private investments, and a focus on both technological architecture and skills development. In addition, it was recognized that the role of globalization, lean manufacturing, and business model innovation has been and will be extremely relevant in shaping and spreading this latest industrial revolution. On the other hand, however, it was pointed out that the lack of skilled workers, financial resources, and organisational culture aimed at innovation may limit the adoption of new advances.

As far as the Italian market is concerned, based on the Bank of Italy's "Survey on Industrial and Service Firms" (containing data on companies with more than 20 employees), several elaborations were carried out. First, in terms of descriptive statistics, it came out that the percentage of Italian companies adopting any I4.0 technologies ranged between 10% and 20%, reaching 30% only in the case of Cloud. In addition, the number of employees in these firms has steadily increased over the years, regardless of a simultaneous growth in the adoption rates. Finally, when analysing the correlation between the adoption of different technologies, a clear distinction emerged between digital and physical advances, with the former generally showing higher correlation values when combined among each other.

Further exploring the features of Industry 4.0 adopters, it emerged that the typical company has two key characteristics: it is large, and it has introduced strategic innovations in recent years. Public policies only partially worked, while age and nationality of the company, which were considered among the most determining factors in the previous analysis, showed little or no statistical evidence. Regarding the three main labour market variables, two analyses were carried out, one concerning the short term, the other involving a longer perspective. The first study showed no significant results in terms of the impact of Industry 4.0 on the annual change of the variables analysed, although documenting a higher level of these variables for adopting companies. The second study, on the other hand, revealed that. adopting companies experienced a higher growth rate of labour productivity compared to wages. According to the theory, this should translate into a reduction of the labour share of income. However, as statistical significance was not found, it can be concluded that the mere implementation of Industry 4.0 is not driving the phenomenon.

BIBLIOGRAPHY

Acemoglu, D., & Restrepo, P. (2017). *Low-Skill and High-Skill Automation* (Working Paper No. 24119). National Bureau of Economic Research.

Acemoglu, D., & Restrepo, P. (2018). *Artificial Intelligence, Automation and Work*. 43.

Acemoglu, D., & Restrepo, P. (2019). Automation and New Tasks: How Technology Displaces and Reinstates Labor. *Journal of Economic Perspectives*, *33*(2), 3–30.

Acemoglu, D., & Restrepo, P. (2020). Robots and Jobs: Evidence from US Labor Markets. *Journal of Political Economy*, 57.

Acemoglu, D., & Restrepo, P. (2021). *Tasks, Automation, and the Rise in US Wage Inequality* (Working Paper No. 28920). National Bureau of Economic Research.

Adolph, S., Tisch, M., & Metternich, J. (2014). *Challenges and Approaches to Competency Development for Future Production*. *12*, 10.

Akst, D. (2013). *What can we learn from past anxiety over automation?*

Amatori, F., & Colli, A. (2013). *Business History: Complexities and Comparisons*. Routledge.

Ancarani, A., Di Mauro, C., & Mascali, F. (2019). Backshoring strategy and the adoption of Industry 4.0: Evidence from Europe. *Journal of World Business*, *54*(4), 360–371.

Atkinson, A. B., Piketty, T., & Saez, E. (2011). Top Incomes in the Long Run of History. *Journal of Economic Literature*, *49*(1), 3–71.

Autor, D., Dorn, D., Katz, L. F., Patterson, C., Booth, C., & Reenen, J. V. (2019). *The Fall of the Labor Share and the Rise of Superstar Firms*. 106.

Autor, D. H. (2015a). *Why Are There Still So Many Jobs? The History and Future of Workplace Automation*. 28.

Autor, D. H. (2015b). *Paradox of Abundance: Automation Anxiety Returns*.

Bank, E. C. (2022). *Monetary policy in the euro area*.

Barkai, S. (2020). Declining Labor and Capital Shares. *The Journal of Finance*, *75*(5), 2421–2463.

Bassanini, A., & Manfredi, T. (2014). Capital's grabbing hand? A cross-industry analysis of the decline of the labor share in OECD countries. *Eurasian Business Review*, *4*(1), 3–30.

Bauer, W., Hämmerle, M., Schlund, S., & Vocke, C. (2015). Transforming to a Hyper-connected Society and Economy – Towards an "Industry 4.0". *Procedia Manufacturing*, *3*, 417–424.

Bezanson, A. (1922). The Early Use of the Term Industrial Revolution. *The Quarterly Journal of Economics*, *36*(2), 343–349.

Bittencourt, V. L., Alves, A. C., & Leão, C. P. (2019). Lean Thinking contributions for Industry 4.0: A Systematic Literature Review. *IFAC-PapersOnLine*, *52*(13), 904–909.

Boyes, H., Hallaq, B., Cunningham, J., & Watson, T. (2018). The industrial internet of things (IIoT): An analysis framework. *Computers in Industry*, *101*, 1–12.

Briguglio, L., & Vella, M. (2014). *Technological Advance and the Labour Share of National Income in the European Union*. 23.

Carbonero, F., Ernst, E., & Weber, E. (2020). Robots Worldwide: The Impact of Automation on Employment and Trade. *Discussion Paper*, 36.

Castelo-Branco, I., Cruz-Jesus, F., & Oliveira, T. (2019). Assessing Industry 4.0 readiness in manufacturing: Evidence for the European Union. *Computers in Industry*, *107*, 22–32.

Cette, G., Devillard, A., & Spiezia, V. (2021). The contribution of robots to productivity growth in 30 OECD countries over 1975–2019. *Economics Letters*, *200*, 109762.

Cette, G., Lopez, J., Presidente, G., & Spiezia, V. (2019). Measuring 'indirect' investments in ICT in OECD countries. *Economics of Innovation and New Technology*, *28*(4), 348–364.

Chiacchio, F., Petropoulos, G., & Pichler, D. (2018). *The impact of industrial robots on EU employment and wages: A local labour market approach*. 36.

Dachs, B., Kinkel, S., & Jäger, A. (2019). Bringing it all back home? Backshoring of manufacturing activities and the adoption of Industry 4.0 technologies. *Journal of World Business*, *54*(6), 101017.

Dauth, W., Findeisen, S., Suedekum, J., & Woessner, N. (2021). The Adjustment of Labor Markets to Robots. *Journal of the European Economic Association*, *19*(6), 3104–3153.

De Loecker, J., Eeckhout, J., & Unger, G. (2020). The Rise of Market Power and the Macroeconomic Implications*. *The Quarterly Journal of Economics*, *135*(2), 561–644.

De Paula Ferreira, W., Armellini, F., & De Santa-Eulalia, L. A. (2020). Simulation in industry 4.0: A state-of-the-art review. *Computers & Industrial Engineering*, *149*, 106868.

De Vries, G. J., Gentile, E., Miroudot, S., & Wacker, K. M. (2020). The rise of robots and the fall of routine jobs. *Labour Economics*, *66*, 101885.

Deakin, S., Malmberg, J., & Sarkar, P. (2014). How do labour laws affect unemployment and the labour share of national income? The experience of six OECD countries, 1970–2010. *International Labour Review*, *153*(1), 1–27.

Dick, S. (2019). Artificial Intelligence. *Harvard Data Science Review*.

Dinlersoz, E., & Wolf, Z. (2018). Automation, Labor Share, and Productivity: Plant-Level Evidence from U.S. Manufacturing. In *Working Papers* (No. 18–39; Working Papers). Center for Economic Studies, U.S. Census Bureau.

Erol, S., Jäger, A., Hold, P., Ott, K., & Sihn, W. (2016). Tangible Industry 4.0: A Scenario-Based Approach to Learning for the Future of Production. *Procedia CIRP*, *54*, 13–18.

Ervural, B., & Ervural, B. (2018). *Overview of Cyber Security in the Industry 4.0 Era* (pp. 267–284).

Estlund, C. (2021). *Automation Anxiety: Why and How to Save Work*. Oxford University Press.

Faber, M. (2018). *Robots and reshoring: Evidence from Mexican local labor markets*.

Frank, A. G., Mendes, G. H. S., Ayala, N. F., & Ghezzi, A. (2019). Servitization and Industry 4.0 convergence in the digital transformation of product firms: A business model innovation perspective. *Technological Forecasting and Social Change*, *141*, 341–351.

Frey, C. B., & Osborne, M. A. (2017). The future of employment: How susceptible are jobs to computerisation? *Technological Forecasting and Social Change*, *114*, 254–280.

Garcia-Lazaro, A., & Pearce, N. (2021). Technology and the Labour Share in Industrialised Economies: A Revisited Analysis. *SSRN Electronic Journal*.

Ghobakhloo, M. (2020). Industry 4.0, digitization, and opportunities for sustainability. *Journal of Cleaner Production*, *252*, 119869.

Gómez, Fuente, D. L., García, Rosillo, & Puche. (2016). *A vision of industry 4.0 from an artificial intelligence point of view*.

Goos, M., Manning, A., & Salomons, A. (2014). Explaining Job Polarization: Routine-Biased Technological Change and Offshoring. *American Economic Review*, *104*(8), 2509–2526.

Graetz, G., & Michaels, G. (2018). Robots at Work. *The Review of Economics and Statistics*, *100*(5), 753–768.

Gray, J. V., Skowronski, K., Esenduran, E., & Rungtusanatham, M. J. (2013). The Reshoring Phenomenon: What Supply Chain Academics Ought to know and Should Do. *Journal of Supply Chain Management*, *49*(2), 8.

Grossman, G. M., & Oberfield, E. (2022). The Elusive Explanation for the Declining Labor Share. *Annual Review of Economics*, *14*(1), 93–124.

Guerriero, M. (2012). *The Labour Share of Income around the World. Evidence from a Panel Dataset*. 56.

Guscina, A. (2006). Effects of Globalization on Labor's Share in National Income. *IMF Working Papers*, *2006*(294).

Hermann, M., Pentek, T., & Otto, B. (2015). *Design Principles for Industrie 4.0 Scenarios: A Literature Review*.

Horváth, D., & Szabó, R. Zs. (2019). Driving forces and barriers of Industry 4.0: Do multinational and small and medium-sized companies have equal opportunities? *Technological Forecasting and Social Change*, *146*, 119–132.

Kaldor, N. (1957). *Capitalist Evolution in the Light of Keynesian Economics*. *18*, 11.

Keynes, J. M. (1930). *Economic Possibilities for our Grandchildren*. 42.

Kinkel, S. (2020). Industry 4.0 and reshoring. In *Industry 4.0 and Regional Transformations*. Routledge.

Klingenberg, C. O., Borges, M. A. V., & Antunes, J. A. do V. (2022). Industry 4.0: What makes it a revolution? A historical framework to understand the phenomenon. *Technology in Society*, *70*, 102009.

Lee, J., Bagheri, B., & Kao, H.-A. (2015). A Cyber-Physical Systems architecture for Industry 4.0-based manufacturing systems. *Manufacturing Letters*, *3*, 18–23.

Mittal, S., Khan, M. A., Romero, D., & Wuest, T. (2018). A critical review of smart manufacturing & Industry 4.0 maturity models: Implications for small and medium-sized enterprises (SMEs). *Journal of Manufacturing Systems*, *49*, 194–214.

Munro, K. (2012). Deconstructing Flame: The limitations of traditional defences. *Computer Fraud & Security*, *2012*(10), 8–11.

Nayyar, A., & Kumar, A. (2019). *A Roadmap to Industry 4.0: Smart Production, Sharp Business and Sustainable Development*. Springer Nature.

Obschonka, M. (2018, March 26). Research: The Industrial Revolution Left Psychological Scars That Can Still Be Seen Today. *Harvard Business Review*.

OECD. (2015). *The Labour Share in G20 Economies*.

OECD. (2019). *ICT investments in OECD countries and partner economies: Trends, policies and evaluation*. OECD.

Perugini, C., Vecchi, M., & Venturini, F. (2017). Globalisation and the decline of the labour share: A microeconomic perspective. *Economic Systems*, *41*(4), 524–536.

Popkova, E. G., Ragulina, Y. V., & Bogoviz, A. V. (2018). *Industry 4.0: Industrial Revolution of the 21st Century*. Springer.

Prem, E. (2015). *A digital transformation business model for innovation*.

Prettner, K., & Strulik, H. (2020). Innovation, automation, and inequality: Policy challenges in the race against the machine. *Journal of Monetary Economics*, *116*, 249–265.

Raisch, S., & Krakowski, S. (2021). *Artificial intelligence and management: The automation–augmentation paradox*. 48.

Ribeiro, J., Lima, R., Eckhardt, T., & Paiva, S. (2021). Robotic Process Automation and Artificial Intelligence in Industry 4.0 – A Literature review. *Procedia Computer Science*, *181*, 51–58.

Rüßmann, M., Lorenz, M., Gerbert, P., Waldner, M., Justus, J., Engel, P., & Harnisch, M. (2015). *Industry 4.0: The Future of Productivity and Growth in Manufacturing Industries*. 20.

Taghavi, V., & Beauregard, Y. (2020). *The Relationship between Lean and Industry 4.0: Literature Review*. 13.

Taniguchi, H., & Yamada, K. (2022). ICT capital–skill complementarity and wage inequality: Evidence from OECD countries. *Labour Economics*, *76*, 102151.

Teixeira, J. E., & Tavares-Lehmann, A. T. C. P. (2022). Industry 4.0 in the European union: Policies and national strategies. *Technological Forecasting and Social Change*, *180*, 121664.

The Economist. (2016). Automation and anxiety.

Von Leipzig, T., Gamp, M., Manz, D., Schöttle, K., Ohlhausen, P., Oosthuizen, G., Palm, D., & von Leipzig, K. (2017). Initialising Customer-orientated Digital Transformation in Enterprises. *Procedia Manufacturing*, *8*, 517–524.

Wallén, J. (2008). *The History of the Industrial Robot*. Linköping University Electronic Press.

Walsh, C. (2004). The productivity and jobs connection: The long and the short run of it. *FRBSF Economic Letter*.

Wilson, D. C. S. (2014). Arnold Toynbee and the Industrial Revolution: The Science of History, Political Economy and the Machine Past. *History and Memory*, *26*(2), 133–161.

Wilson, H. J., Daugherty, P. R., & Morini-Bianzino, N. (2017). *The Jobs That Artificial Intelligence Will Create*. 5.