DEPARTMENT OF BUSINESS AND MANAGEMENT

Master Thesis in International Economics and Industrial Dynamics

THE ICTs REVOLUTION: ROUTINE-BIASED TECHNICAL CHANGE AND SOCIAL INEQUALITY

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Introduction

The debate on "technological unemployment"[1] has always accompanied the history of industrial economics. The effects that the new technologies may have on labour market dynamics in terms of employment levels, workforce composition and wage inequality have caused, and they are still causing, concerns among economists and experts enough to make them an important topic for discussion. The aim of this thesis is to outline how the labour market dynamics changed as a result of the introduction of new technologies into production processes, starting from the 19th century revolution up the most recent phenomenon of the Industry 4.0. To do that, different and conflicting theories on the relationship between employment and technologies will be analysed. Economists have always wondered about the effects of technology in terms of employment. Some argue that the introduction of technological innovations in production processes has a negative effect since it involves the substitution of human labour by machines. Others, however, consider the substitution effect a short-term phenomenon. Over time, the market mechanisms will lead to the development of new productive sectors and, therefore, new job opportunities could be created. One of the first forms of protest against the introduction of new machines into production processes is represented by the Luddism. During the first industrial revolution some British weavers attacked the mechanical looms because of the fear that these industrial machines could stole their jobs. The machines, in fact, were viewed as a threat to workers' employment and, therefore, they were considered responsible for low wages and unemployment. The "End of Work"[2] has been announced many times but it never materialized: from the beginning of the industrial era, in fact, there has been a simultaneous increase in productivity and employment. However, technologies are improving at exponential rate, just as described by Gordon Moore, and there is no way to predict what the future implications will be[3]. Beyond the quantitative aspect of technological progress, there exists an extensive body of economic literature on the qualitative effects of innovation on employment, namely which workers are favoured by the

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[1] Keynes, J. (1931). *Essays in persuasion*. London: Macmillan, pp.321-334.
[2] Rifkin, J. (1995). *The End of Work: The Decline of the Global Labor Force and the Dawn of the Post-Market Era*. Putnam Publishing Group.
[3] Moore, G. (1998). *Cramming More Components Onto Integrated Circuits*. Proceedings of the IEEE, 86(1).

introduction of technologies into production processes. Even on this topic, two opposing currents of thoughts can be identified. According to the skill-biased technical change hypothesis, digital technologies complements the job of high-skill workers, while replacing less-skilled ones. Conversely, the routine-biased technical change states that digitization replaces medium-skill workers who perform routine activities. However, technological progress is complementary to workers who perform non-routine activities, providing a possible explanation of the recent phenomenon of the polarization of labour market. Even if it cannot be the only one. Nowadays, however, the importance of the routine-biased technical change hypothesis is waning. This is because the introduction of the technologies of Industry 4.0 into production processes led to a blurring of boundaries between routine and non-routine task. Many of the activities classified as "non-routine" can in practice be automated and executed by increasingly intelligent machines and robots. What the implication of the new wave of innovation will be is being dealt with in the final chapter.

The thesis is structured as follow: in the first chapter, the quantitative and qualitative impact of the "first machines age"[4] technologies on employment will be analysed, the second chapter is focused on the role that information and communications technologies (ICTs) played in labour market dynamics, the third chapter explores how Industry 4.0 will affect employment levels and workforce composition, building upon on recent researches and particularly on Frey and Osborne's task model.

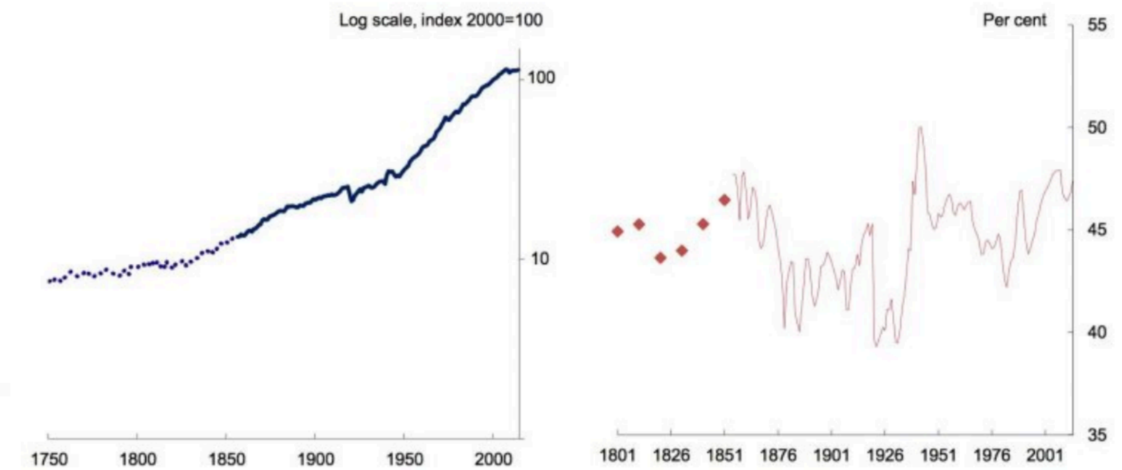
[4] Brynjolfsson, E. and McAfee, A. (2014). *The second machine age*. 1st ed. New York: W. W. Norton & Company.

1. From the steam engine to the "second machine age"

1.1 The first industrial revolution

Until the second half of the 1700s, productive activities were tied to a traditional system based upon agriculture, craftsmanship and commerce. The advent of the steam engine, developed by Thomas Savery in 1689 and subsequently enhanced by James Watt, marked a turning point in history. It made it possible, in fact, to transform the energy given off by steam into mechanical power, allowing to overcome the constraints of the physical world. The steam engine is usually considered to be the symbol of the first industrial revolution which, in turn, can be defined as a radical change in economy and society that occurred from 1789 to 1880[5]. The new engine was applied at first to the textile production, making for more efficient organisation of work, and, subsequently, to mining and transports. However, the importance that is placed on the steam engine has to be reduced since productivity gains deriving from its exploitation emerged only at a later stage, as we will see later on in this chapter. The first phase of the revolution was characterized indeed by other important innovations such as the human-powered spinning-jenny and the water-frame (which made use of the force of water)[6]. Therefore, it should be clear that the factory system developed before the steam power became widespread. Productivity grew during this period, showing the benefits of the new method of the division of labour (which was adopted in the new-born factories), as it can be seen from the picture below.

[5] De Simone, E. (2012). *Storia economica: dalla rivoluzione industriale alla rivoluzione informatica*. 4th ed. Milano: Franco Angeli, pp. 15-59.
[6] De Simone, E. (2012). *Storia economica: dalla rivoluzione industriale alla rivoluzione informatica*. 4th ed. Milano: Franco Angeli, pp. 15-59.



Figure[7]

On the x-axis is the period of time, on the y-axis is the productivity of labour (on the left) and the percentage of people employed to population (on the right). Even if these data concern the development of the U.K. economy, where the industrial revolution originally begun owing to the presence of a number of favourable conditions (such as the availability of capital to invest and the cheap labour force, high demand for products and technological innovations)[8], similar trends have been common in many other countries. The graphs above show that the productivity and the employment growth rates increased progressively over time. Therefore, from the information set out above it appears that technological progress has been a crucial factor in economic growth, just as demonstrated by Robert Solow (whose endogenous growth theory will be analysed in the next chapter in greater detail). Moreover, the long-term impact of technology on employment has been positive: more jobs were created than lost. In the short-term, however, the revolution has been painful for the workforce, accompanied as it was by redundancies and switches to often socially insecure conditions of employment. Starting from the XVIII century, workers and

[7] Bank of England (2016). *A millennium of macroeconomic data*. [online] Bankofengland.co.uk. Available at: https://www.bankofengland.co.uk/statistics/research-datasets [Accessed 26 May 2018].

[8] De Simone, E. (2012). *Storia economica: dalla rivoluzione industriale alla rivoluzione informatica*. 4th ed. Milano: Franco Angeli.

machines started to be concentrated into large production facilities that were run by rich merchant-entrepreneurs. On one hand, the factory system created new job opportunities for proletariats. On the other hand, however, artisans (mainly framework-knitters) lost their jobs. Craftsmen displaced by technological progress moved towards traditional services whose labour supply increased accordingly. As a result of that, the traditional sector wages decreased, partly fuelling migration towards the United States of America (USA)[9]. Therefore, craftsmen's income and their labour demand were penalised by the technological revolution. The job opportunities provided by the factory not seemed to compensate for falling craftsman labour demand: in fact, the number of craftsmen replaced by the introduction of the new machines into production process was greater than the number of those who found a job in the factory. The widespread use of machines resulted in a situation where supply exceeded demand, leading to period crisis and unemployment. All this incited workers' protests against the introduction of machines into production processes, whose most notorious manifestation was the "Luddism"[10]. Between 1811 and 1817 some British weavers attacked the mechanical looms introduced during the first industrial revolution because of the fear that these industrial engines could stole their jobs. The machines, in fact, were viewed as a threat to workers' employment and, therefore, they were considered responsible for low wages and unemployment. At this historic time, the "technological unemployment"[11] was mainly caused by the absence of compensation mechanisms. At first, the technological revolution did not lead to the creation of new economic sectors. Only in the second phase of the first industrial revolution, new sectors were created from the steam engine exploitation: the railway and the shipbuilding ones[12]. In 1814, George Stephenson designed the first locomotive for the transport of materials whereas in 1830 the Liverpool-Manchester railway line used for passenger transportation was developed. They helped to create new job opportunities for

[9] Cipriani, A., Gramolati, A. and Mari, G. (2018*). Il lavoro 4.0: La Quarta Rivoluzione industriale e le trasformazioni delle attività lavorative*. Firenze: Firenze University press.
[10] De Simone, E. (2012). *Storia economica: dalla rivoluzione industriale alla rivoluzione informatica*. 4th ed. Milano: Franco Angeli.
[11] Keynes, J. (1931). *Essays in persuasion*. London: Macmillan, pp.321-334.
[12] Cipriani, A., Gramolati, A. and Mari, G. (2018*). Il lavoro 4.0: La Quarta Rivoluzione industriale e le trasformazioni delle attività lavorative*. Firenze: Firenze University press.

skilled workers. High railway and ships demand, in turn, led to the development of the steel industry in the late 1850s.[13]

The view that the introduction of machines into production processes led to technological unemployment and people's impoverishment has been questioned by many economists, among which Joel Mokyr. In the paper "The History of Technological Anxiety and the Future of Economic Growth"[14], he claimed that technology may destroy labour demand for certain categories of workers without, however, damaging long-term total employment. "*In fact, a closer examination of the better-known British protests of the day that were supposedly focused technological innovations in textile, like the Luddite (1811-16) and Captain Swing (1830-32) riots, the role actually played by the concerns of laborers about being replaced by machinery has been greatly exaggerated*"[15]. According to the author, a distinction between short-term and long-term effects brought by technological innovations should be made. While accepting that technological progress can lead to the technological unemployment over the short-term, he believes that new jobs will be created over the long-term through the compensation effects. Empirical data seemed to confirm that line of though. Therefore, the unemployment brought about by the introduction of machines in the new born factories would be just a short-term phenomenon. Over time, in fact, market mechanisms led to the development of new productive sectors and, consequently, new job opportunities were created such as those of mechanics, supervisors and accountants. Luddites' fears proved to be baseless and, for this reason, it is common to hear about the "Luddite fallacy". Beside questions of employment impact of the 19th century innovations, it is certain that the new factory system negatively affected working conditions. Employees were forced to work up to 16 hours a day. They were crammed together in close spaces scarcely even able to move. The windows of the factories were tight, and they were often kept closed: the temperature inside was about 26-30 degrees. There was no safety: accidents were frequent.

[13] De Simone, E. (2012). *Storia economica: dalla rivoluzione industriale alla rivoluzione informatica*. 4th ed. Milano: Franco Angeli.
[14] Mokyr, J., Vickers, C. and Ziebarth, N. (2015). *The History of Technological Anxiety and the Future of Economic Growth: Is This Time Different?*. Journal of Economic Perspectives, (29), pp.31-50.
[15] Mokyr, J., Vickers, C. and Ziebarth, N. (2015). *The History of Technological Anxiety and the Future of Economic Growth: Is This Time Different?*. Journal of Economic Perspectives, (29), pp.31-50.

Every delay was punished. Breaks were not allowed. Neither women and children were spared from those inhuman working conditions. Kids were employed in factories at the age of eight or nine years old and they were forced to about 12 hours a day and sometimes through the night. The whole situation was made worse by problems relating to urbanization. Labourers were forced to live in overcrowded and bad hygienic conditions. Furthermore, the low salaries did not allow for an appropriate lifestyle.[16] This led to the development of the first trade unions. They were organisations aimed at protecting working condition and their social and civil life. "*However, it was not only the new trade unions (...) who were appalled by the long hours of work, but also more Enlighted industrialists such as Robert Owen, Josiah Wedgwood, and Samuel Whitbread. These entrepreneurs, who were among the most successful, argued that technical and organisational innovations, together with improved education and training, and paternalistic reforms in the enterprise would raise productivity more than the crude lengthening of the working day*"[17]. These principles were applied by Robert Owen at his New Lanark mill where he introduced a health insurance fund, he built comfortable accommodations and created a "Grand National Consolidated Trade Union" (GNCTU). Even if that organisation was not a great success it represented a major step on the road towards the recognition of the rights of the working-class people[18].

Reference is made to a significant economic growth when talking about the first industrial revolution. In Adam Smith's studies, it is noted that countries' wealth and higher productivity are dependent on the specialisation of workers who, by performing single and routine tasks, acquire greater dexterities and, in turn, are able to increase the quantity of their work[19]. A low level of education is required in the performance of these basic tasks. As a consequence of that, the new working-class of the first industrial revolution was composed primarily of unskilled people. In fact, while in the crafts' workshop production required a high level of

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[16] Freeman, C. and Louçã, F. (2001). As times goes by: from the industrial revolutions to the information revolution. New York: Oxford University Press, pp. 171-175.
[17] Freeman, C. and Louçã, F. (2001). As times goes by: from the industrial revolutions to the information revolution. New York: Oxford University Press, p. 172.
[18] Freeman, C. and Louçã, F. (2001). As times goes by: from the industrial revolutions to the information revolution. New York: Oxford University Press, p. 172.
[19] Smith, A. and Cannan, E. (1994). *An inquiry into the nature and causes of the wealth of nations*. New York: Modern Library.

professional expertise, those working in the factory did not have to know all the stages of labour production because they had to deal with basic functions. Therefore, the main characteristic of the 19th century revolution is that it led to the deskilling of the workforce. Machines do not always require higher skills. The technological revolution can also be "deskilling" and, therefore, it can increase labour demand for unskilled workers since learning how to use new technologies does not require high skills. The technological progress brought about by the first industrial revolution was deskilling in that skilled craftsmen were replaced by machines in carrying out their activities, which, in turn, were operated by unskilled workers. Indeed, it was not necessary to study to put machines into action: learning how to perform these functions demanded just a few hours. This trend continued in the second industrial revolution when the assembly line and the scientific management appeared, as we will see in the next paragraph. The pin factory is perhaps the best example to explain the new phenomenon of the division of labour (which is the source of the deskilling of the workforce). It made it possible to obtain a production 4.800 times greater than that obtained from a single craftsman (which, instead, is able to produce just one pill in a day)[20]. In the pin factory, work was divided into eighteen distinct activities carried out by different people: "*one man draws out the wire, another straights it, a third cuts it, a fourth points it, a fifth grinds it at the top for receiving, the head; to make the head requires two or three distinct operations; to put it on is a peculiar business, to whiten the pins is another; it is even a trade by itself to put them into the paper"*[21]. According to the author, there are at least three reasons why the division of labour lead to an increase in production:

- Higher worker's dexterity: "*by reducing every man business to some on simple operation, and by making this operation the sole employment of his live, necessarily increased very much the dexterity of the workman*" [22]. Therefore, by dividing

[20] Smith, A. and Cannan, E. (1994). *An inquiry into the nature and causes of the wealth of nations*. New York: Modern Libra.
[21] Smith, A. and Cannan, E. (1994). *An inquiry into the nature and causes of the wealth of nations*. New York: Modern Libra, p. 9.
[22] Smith, A. and Cannan, E. (1994). *An inquiry into the nature and causes of the wealth of nations*. New York: Modern Libra, p. 11.

production process in a number of simple tasks, individuals become more expert in their own branch.

- The time-savings derived from reducing the time required for switching from one production to another one. Since different productions require different tools and work stations, it seems clear that time is wasted moving from one to another.
- The presence of new machines that facilitate human labour. The steam engine should be mentioned in this respect. It allowed to make production process simpler and faster.

For all these reasons, the new organisational method of the "division of labour" that was adopted in the factory system allowed for a productivity increase and, consequently, it led to economic growth. Therefore, the introduction of new technologies into production processes and the exploitation of new energy resources led to an acceleration of the U.K. productivity growth, giving rise to the first industrial revolution[23]. However, according to a more recent interpretation, it would have been more correct to talk of an "industrial transition" since the effect of innovations arose only in the second half of the century that followed. Productivity gains would, therefore, be overestimated. Revisions to productivity estimates in United Kingdom, in fact, showed an annual per capita income growth slightly higher than pre-industrial age, whereas productivity growth rate remained at the same level (productivity increased by 0,14% between 1760 and 1800)[24]. Furthermore, that slight productivity growth was entirely attributable to the textile industry where innovations like the flying shuttle developed by John Kay, the spinning jenny developed by James Hargreaves and the water frame invented by Richard Arkwright improved the efficiency of the production process. The latter, in particular, allowed for substituting the human muscle strength with the force of water. The steam engine, instead, had a slow diffusion due to the technical constraints and the high costs of the first engines. "*The great majority of cotton mills were still using water*

[23] Studies show that productivity growth rate prior to the agricultural revolution was about 0,1-0,2% per year, whereas it doubled in subsequent periods cf. Allen, R. (2000). *Economic Structure and agricultural productivity in Europe, 1300-1800.* European Review of Economic History 4 (1), pp. 1-26.

[24] Floud, R., Humphries, J. and Johnson, P. (2014). *The Cambridge economic history of modern Britain*. Cambridge: Cambridge University Press, p. 8.

power in 1800 (…) the really widespread diffusion of the steam engine and the mechanization of many other industries depended on greatly improved high pressures steam engines, which become available in the late 1830s and 1840s"[25]. Even if the steam engine was invented at the beginning of the 18th century, it was not applied in production processes until the 1850s. Therefore, in this first phase, productivity increase was led by minor innovation, mainly those applied in the textile sector.

In general, the technological potential of the first industrial revolution, and its ability to boost productivity, is considered to be less important compared to that of the second one. The technologies of first industrial revolution, in fact, affected mainly the textile industry, by not investing other manufacturing sectors to the same extent. Moreover, within the same textile industry, not all types of spinning were mechanized: this was the case for the wool-spinning which was automated only afterwards due to the material's least resistance[26]. Therefore, only few sectors experienced productivity growth arising from the technological progress exploitation, whereas the majority of industries were isolated from the technological revolution and unable to reap its benefits.

"*The British economy as a whole was changing much more slowly than its most dynamic parts such as cotton and machine tools, because growth was 'diluted' by slow-growing sectors (…) It is hardly surprising that it took until 1830 or 1840 for the economy-wide effects of the industrial revolution to be felt*"[27].

The textile industry realised its strongest productivity growth since the year 1770s at a rate of 3.1% per year[28]. The total factor productivity of the textile sector, in fact, increased significantly over the period concerned, and it represented approximately 70% of the total productivity increase, as it can be seen from the picture below.

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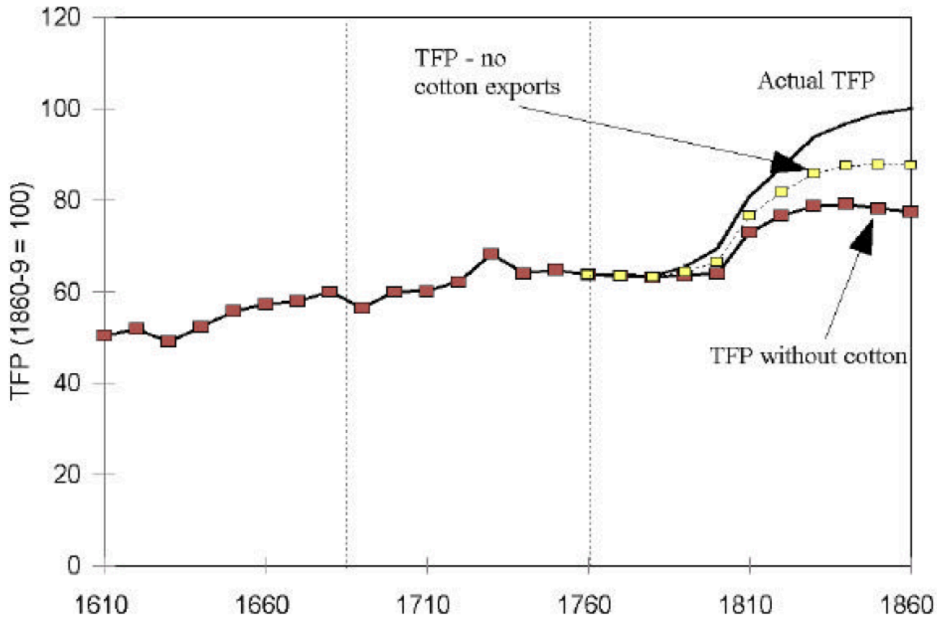
[25] Freeman, C. and Louçã, F. (2001). As times goes by: from the industrial revolutions to the information revolution. New York: Oxford University Press, p. 201.

[26] Cipriani, A., Gramolati, A. and Mari, G. (2018*). Il lavoro 4.0: La Quarta Rivoluzione industriale e le trasformazioni delle attività lavorative*. Firenze: Firenze University press.

[27] Floud, R., Humphries, J. and Johnson, P. (2014). *The Cambridge economic history of modern Britain*. Cambridge: Cambridge University Press, p. 12.

[28] Clark, G. (2001). *The Secret History of the Industrial Revolution*. Department of Economics Working Papers, p. 50.



Figure[29]

On the y-axis is the productivity growth rate (with and without cotton's contribution and exports), on the x-axis is the period of time ranging from 1610 to 1860.

"*Thus nearly two thirds of the productivity growth rate can be explained by essentially one set of innovations, and by industries that employed less than 10% of the labour force in 1851. The great mass of the economy, including agriculture, construction, services, and most manufacturing saw very little productivity increase"*[30].

Albeit belatedly, unquestionable benefits have been achieved through the steam engine exploitation. For example, in the mining sector, the steam pumper was used to resolve the rainwater infiltration problem and, therefore, it allowed to improve coal extraction, making

[29] Clark, G. (2001). The Secret History of the Industrial Revolution. Department of Economics Working Papers, p. 51.
[30] Clark, G. (2001). The Secret History of the Industrial Revolution. Department of Economics Working Papers, p. 53.

it more efficient. Prior to 1712, in fact, it was not possible for the miners to collect the coal that was at some depth since the tunnel was filled with water. Furthermore, in the transport sector, the locomotive made the transport of the goods more efficient and riskless whereas steam vessels allowed for reducing the duration of the journey. In turn, the improved means of transport allowed for the enlargement of the market that, following the Corn laws abolition (1846), opened up for free trade. Already in 1776, the economist Adam Smith exalted free trade by claiming that State interventions are not needed as the market can manage on its own through an invisible hand[31]. Self-interest actions, in fact, benefit general interest: people want to increase their profits and, by doing so, they increase the wealth of nations. In fact, the gross domestic product (GDP) of a country is given by the sum of the revenues of his industries. "*By preferring the support of domestic to that of foreign industry, he intends only his own security; and by directing that industry in such a manner as its produce may be of the greatest value, he intends only his own gain, and he is in this, as in many other cases, led by an invisible hand to promote and end which was no part of his intention*"[32]. As a consequence of that, according to the author, countries should adopt a laissez-faire approach: it is always preferable to allow the market to operate unimpeded. David Ricardo in turn came up with the theory of comparative advantage, showing the convenience of the international division of labour. To briefly illustrate it, let's consider two countries: Home and Foreign. Both produce the same two goods. According to the author, even if Home would be able to produce both goods at a lower cost compared to Foreign, it would turn better to specialize in the production of one good and trade it for the other since the advantage that would have ensued would be greater than that obtained if countries would have produced both of them[33].

In general, the steam engine enabled to overcome the limitations set out by water- and wind-mills which required a precise position of the factory. Conversely, the new engine could be placed wherever it was needed, allowing to concentrate production in town (where labour force was abundant) instead of countryside. Moreover, the new engine was universal in its

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[31] Smith, A. and Cannan, E. (1994). *An inquiry into the nature and causes of the wealth of nations*. New York: Modern Library.

[32] Smith, A. and Cannan, E. (1994). *An inquiry into the nature and causes of the wealth of nations*. New York: Modern Library.

[33] Ricardo, D. (1817). *On the principles of political economy and taxation*. London: John Murray

application and not bound by weather conditions. Unlike Watt's engine, in fact, the strength of wind or water could not be controlled or increased to individual requirements: sometimes it was lacking, other times it was not sufficient[34]. In conclusion, only when the steam power developed, closeness to streams and other watercourses was no longer needed, and, therefore, energy could be created everywhere and in any season, leading to the development of the modern factory system.

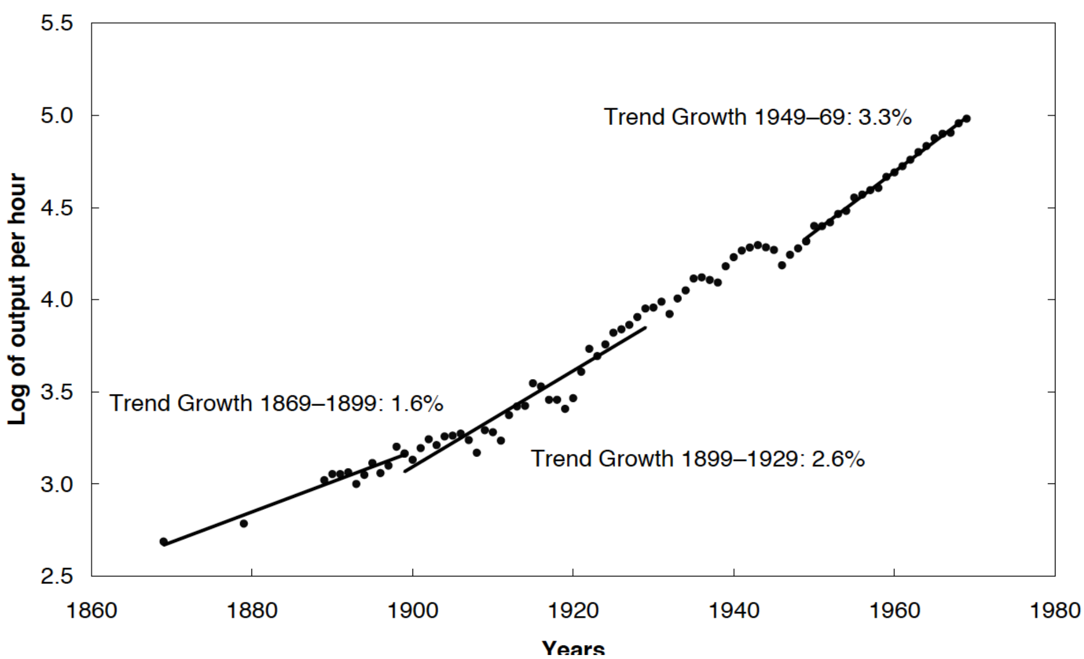
1.2 The second industrial revolution

Starting from the second half of the XIX century, a new historic era begun: the second industrial revolution. Scientific progress became increasingly important for countries' economic and social development, giving rise to new productive sectors, such as the electricity and chemical industries, and revolutionising the existing ones. Electricity, combustion engine, cars, telegraph are just few of the several innovations developed during this period. The new economic scenario saw the rise of two industrial powers: Germany and United States of America (USA), where the availability of considerable resources and the liberal political approach promoted industrial development.

In general, the second industrial revolution is considered to be more important compared to the first one since the technological renewal invested all sectors of the economy. "*After this revolution began, however, several decades passed before this revolution led to a new economy characterized by faster growth in productivity growth, measured by output per hour*"[35]. Therefore, despite numerous technologies were developed at that time, productivity gains took their time to show up. This was mainly due to the slow pace at which new technologies have been adopted. Furthermore, learning how to make better use of the technology is time-consuming. In fact, new ways of organizing work are needed to take

[34] Marx, K. and Eugenio, S. (1968). *Il capitale*. Roma: Newton Compton Editori.
[35] Atkeson, A. and Kehoe, P. (2001). *The transition to a new economy after the second industrial revolution*. NBER Working Paper series, p. 2.

advantage of innovations and this can take some time since entrepreneurs may be reluctant to discard the old approach. Only if the technological progress is used in combination with relative organisational changes it will be able to produce noticeable results. A good example of this can be seen in the electricity whose benefits have been limited until the design of the factory plant changed, as documented by several authors[36]. The unit drive system, which replaced the old unit drive system, enabled to place machinery "*so as to handle materials according to the natural sequence of manufacturing operation, rather than according to physical placement of shafts (…) Moreover, once the shafts in the direct-drive system became unnecessary, plants (…) [were] designed with improved ventilation, illumination, and cleanliness and to accommodate overhead electric cranes, which were thought to revolutionize materials-handling*"[37]. Productivity growth was achieved in this way, as it shown in the picture below derived from the U.S. Department of Commerce (1973) data:



[36] David, P. (1990). *The Dynamo and the Computer: An Historical Perspective on the Modern Productivity Paradox*. The American Economic Review, 80(2), pp.355-361.
[37] Atkeson, A. and Kehoe, P. (2001). *The transition to a new economy after the second industrial revolution*. NBER Working Paper series, p. 9.

Figure[38]

On the y-axis is the productivity growth in the U.S. manufacturing industry (measured as output per hour), on the x-axis is the period of time. Prior to the 1899, productivity growth rate was only 1.6%. In this period, machines were driven by energy derived from water and steam. Starting from the 1890s, the old sources of mechanical power were gradually replaced by electricity, leading to a small increase in productivity (of around 0,63%). Strong productivity growth was achieved only when electricity became widely spread and the unit drive system was introduced in the factory layout. It is precisely for this reason that productivity gains arising from electricity exploitation showed up only in the late 1950, 50 years after its invention[39]. Therefore, we can conclude that "*it is ahistorical to think about industrial revolutions as events that abruptly raise the rate of sustained growth by a considerable amount. Most of the effects of invention and diffusion on income per capita or economic welfare are slow in coming and spread out over long periods*"[40]. Besides product innovations previously mentioned, the second industrial revolution was also characterized by process innovations. Among these, the scientific organisation of labour (also known as task management) merit more specific detail. The most important theorist of this approach was Frederick W. Taylor. According to him, the most efficient and cost-effective production method consists of separating the production cycle into a number of disparate activities to be measured and programmed, which are performed by different actors. Adam Smith had already shown the benefits of the division of labour in his work "The wealth of Nations", by taking as an example the pin factory[41]. However, the scientific management of

[38] Atkeson, A. and Kehoe, P. (2001). *The transition to a new economy after the second industrial revolution*. NBER Working Paper series, p. 41.
[39] Atkeson, A. and Kehoe, P. (2001). *The transition to a new economy after the second industrial revolution*. NBER Working Paper series, p. 20.
[40] Floud, R., Humphries, J. and Johnson, P. (2014). *The Cambridge economic history of modern Britain*. Cambridge: Cambridge University Press, p. 5.
[41] Smith, A. and Cannan, E. (1994). *An inquiry into the nature and causes of the wealth of nations*. New York: Modern Library.

work differs from the mere implementation of the division of labour in that each activity is planned out by the management and, therefore, employees have to follow precise and detailed instructions within a reasonable time. Taylor believed that the American economy was suffering due to the inefficient way of carrying out productive activities and that "*the remedy for this inefficiency lies in systematic management, rather than in searching for some unusual or extraordinary man*"[42]. The new organisation of labour (or "*one best way*"[43]) proposed by Taylor is based on four main points:

- In contrast to the past, each activity must be programmed and theorized so that employees can follow accurate and homogeneous instructions instead of "learning by doing". Therefore, management must plan ahead the work to be done, by applying a scientific method. For each task, it is necessary to specify "*not only what is to be done but how it is to be done and the exact time allowed for doing it. And whenever the workman succeeds in doing his task right, and within the time limit specified, he receives an addition of from 30 per cent to 100 per cent to his ordinary wages*"[44]. In the past, workers carried out their tasks in an autonomous and independent manner, by deciding their own times and working methods. Here, instead, they are deprived of all power to take decisions.
- Employees have to be trained on the new techniques and new working methods to be adopted, whereas, in the past, they were expected to learn everything on their own.
- Collaborative working relations have to be developed between workers and management.
- "*There is an almost equal division of the work and the responsibility between the management and the workman. The management take over all work for which they are better fitted than the workman, while in the past all of the work and the greater part of the responsibility were thrown upon the men*"[45]. This means that the ideation

[42] Taylor, F.W. (1911). *The Principles of Scientific Management*. Cosimo Classics.
[43] Taylor, F.W. (1911). *The Principles of Scientific Management*. Cosimo Classics, p. 2.
[44] Taylor, F.W. (1911). *The Principles of Scientific Management*. Cosimo Classics, p. 14.
[45] Taylor, F.W. (1911). *The Principles of Scientific Management*. Cosimo Classics, p. 13.

phase has to be kept separate from the execution one. In particular, management have to deal with planning the activity, workers have to deal with executing it.

The scientific organisation of labour allows for eliminating all slow and unnecessary movements, while collecting faster and better actions into a user manual. Workers must comply with the time limits and the motion standards imposed by the management, otherwise they will be penalized in terms of wages: the less productive the worker is the lower the salary will be. Workers will commit themselves to performing their jobs to full capacity if they can earn higher wages (in fact, money is a motivating factor). As a result of that, time and actions are reduced and optimized, determining a more efficient and cost-effective way of carrying out productive activities[46]. The practical implementation of Taylor's scientific management is known as Fordism. The term is named for Henry Ford who applied scientific management principles to his car industry in Highland Park, by developing a new production method: the assembly line. Through a conveyor belt, material was moved from one work station to the another one, enabling time-savings since workers' movements were minimized. Therefore, workers performed simple and repetitive tasks by standing still in their station. Henry Ford's assembly line is the first example of mass production: it allowed to produce large quantities of standardized products at a very low cost. On one hand, this production method made a great use of unskilled workforce since high-skills were not required in the performance of basic assembly and operative tasks. In fact, the percentage of unskilled workers employed in manufacturing industries went from 57.5% in 1850 to 65.4% in 1910. But it started to decrease thereafter as more and more functions were mechanized[47]. On the other hand, the introduction of the scientific management in the factory system stimulated the rise of a professional manager class and, therefore, it was accompanied by an increase in the number of skilled professionals called to oversee the unskilled workers' activities: "*as the establishment became larger in size and served geographically expanded markets, managerial tasks increased in number and complexity*"[48]. At the same time, the advent of the

[46] Taylor, F.W. (1911). *The Principles of Scientific Management*. Cosimo Classics.
[47] Katz, L. and Margo, R. (2013). *TECHNICAL CHANGE AND THE RELATIVE DEMAND FOR SKILLED LABOR: THE UNITED STATES IN HISTORICAL PERSPECTIVE*. NBER WORKING PAPER SERIES, p. 60.
[48] Katz, L. and Margo, R. (2013). *TECHNICAL CHANGE AND THE RELATIVE DEMAND FOR SKILLED LABOR: THE UNITED STATES IN HISTORICAL PERSPECTIVE*. NBER WORKING PAPER SERIES, p. 60.

steam power, at first, and the electric motor, subsequently, was accompanied by a growing demand for skilled labour. In fact, the steam- and electric- powered machinery required the contribution of skilled and educated workers to perform installation and maintenance services. As technologies became more advanced, the greater skills were required to operate the new machines. A study conducted by Claudia Goldin and Lawrence Katz in 1996 showed that the more capital- and electric-intensive industries were, the more human capital was employed in production processes.[49] The percentage of skilled workers employed in manufacturing went from 3% in 1850 to 12% in 1910 and to 28% in 1960[50]. This number is far even greater if we consider the economy as a whole: the percentage of skilled workforce went 42.5% in 1850 to 48,2% in 1910 and to 61.7% in 1960[51]. Even if manufacturing industries kept on employing a great number of unskilled workers, the aggregate share of low skill jobs fell while skilled employment rose monotonically from 1850 to 1910. The new-born electrical, oil, chemical, machinery, construction (which was a consequence of the urbanisation phenomenon) and media sectors were relatively intensive in the use of skilled labour[52]. Therefore, the 20th century economy seemed to have followed an upgrading skill pattern (which have continued to the present day), denying the deskilling trend that characterized the first industrial revolution. During the first industrial revolution the skilled labour of craftsmen was replaced by the introduction of new technologies operated by unskilled workers. In the factory system, craftsmen's activities, in fact, were broken up into smaller sequences requiring more workers but fewer skills. Conversely, the hallmark of second industrial revolution was the establishing of a complementary relationship between technology and human labour. At that historical time, an increase in the supply of skilled workers prevented the development of a significant gap between the wages paid to skilled and unskilled workers. It was therefore crucial to countervail the effects arising from the growing demand of skilled labour. "*The growth in the supply of skills was largely due to the*

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[49] Goldin, C. and Katz, L.F. (2009). *The race between education and technology*. Cambridge, Mass.: Belknap.

[50] Katz, L. and Margo, R. (2013). *TECHNICAL CHANGE AND THE RELATIVE DEMAND FOR SKILLED LABOR: THE UNITED STATES IN HISTORICAL PERSPECTIVE*. NBER WORKING PAPER SERIES, p. 60.

[51] Goldin, C. and Katz, L.F. (2009). *The race between education and technology*. Cambridge, Mass.: Belknap.

[52] The percentage of unskilled employment in the aggregate economy went from 57.5% in 1850 to 51.8% in 1910 and 44% in 1920. From: Katz, L. and Margo, R. (2013). *TECHNICAL CHANGE AND THE RELATIVE DEMAND FOR SKILLED LABOR: THE UNITED STATES IN HISTORICAL PERSPECTIVE*. NBER WORKING PAPER SERIES, p. 60.

increased educational attainment of successive cohorts fuelled by increased access to public high schools in the early twentieth century and later to college and universities. The upshot of these factors was the educational wage differentials narrowed from 1915 to 1980"[53]. At this point, we can ask ourselves why the 19th century technologies favoured unskilled labour whereas the 20th century ones increased the demand for skilled workers. There are two theories about this. According to one line of thought, technology is an exogenous factor. The XIX century technologies were deskilling because the "*technological frontier (…) only enabled the invention of skill-replacing techniques*"[54]. Conversely, the technological progress of the XX century resulted in the creation of devices requiring skilled labour. An alternative theory, which was supported also by Daron Acemoglu, holds that technology is an endogenous factor and it builds upon incentives. This means that technological progress reflects the availability of skills. Therefore, "*the emergence of the most skill- replacing technologies of the past two-hundred years, the factory system, coincided with a large change in relative supplies. This time, there was a large migration of unskilled workers (…) [which] created profit opportunities for firms to exploit by introducing technologies that could be used with unskilled workers*"[55]. Conversely, the large supply of skilled workforce of the XX century made it profitable to develop skill-intensive technologies. Therefore, not only technological progress affects the demand for skill, but also labour supply, either skilled or unskilled, may have exerted some influence over technological developments.

To end this chapter, another aspect of the new production method of the scientific management should be mentioned. The assembly line brought the workforce alienation to the extreme. Whereas before workers could organise the way to perform their task, now the ideation phase is separated from the execution one, reducing workers to mere enforcers of management decisions. While the craftsman was responsible for the entire production process those working in the factory had no decision-making power and they were limited to perform a clearly identifiable stage in the production process. Indeed, already in 1844, Karl

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[53] From: Katz, L. and Margo, R. (2013). *TECHNICAL CHANGE AND THE RELATIVE DEMAND FOR SKILLED LABOR: THE UNITED STATES IN HISTORICAL PERSPECTIVE*. NBER WORKING PAPER SERIES, p. 38.
[54] Acemoglu, D. (2002). *Technical Change, Inequality, and the Labor Market*. Journal of Economic Literature, 40(1), p. 11.
[55] Acemoglu, D. (2002). *Technical Change, Inequality, and the Labor Market*. Journal of Economic Literature, 40(1), p. 7.

Marx denounced the division of labor and the private property for workers' alienation through his work "The Economic and Philosophic Manuscripts"[56]. According to the author, there are four types of alienation generated by capitalism:

- First, the worker does not have the ownership of the goods he produces and, therefore, he has no control over them. They belong to the capitalist.
- Second, work is not a spontaneous activity, but it is motivated by the need to make some money to live. "*It is therefore not the satisfaction of a need; it is merely a means to satisfy needs external to it*"[57]. This results in the worker's alienation from his own activity.
- Furthermore, since the individual works for someone else, he has to comply with times and tasks being imposed on him. Therefore, work affects human behaviour since the worker is not free to act for himself and he cannot take his own decisions, but it has to follow the instructions of the employer. As such, worker becomes alienated from his self-being.
- Finally, the employer exploit employee in order to increase his profit and this conflictual relationship leads the worker to feel alienated from human relationships.

For all these reasons, "*the worker sinks to the level of a commodity and becomes indeed the most wretched of commodities*"[58]. This kind of alienation of the workforce appeared during the first industrial revolution when the factory system and the division of labour were developed, and it reached its peak during the second industrial revolution with the advent of the scientific management and the assembly line. In the original factory system working activity was divided among employees who were able to decide how to best perform their actions. With the scientific management, workers can no longer manage the phase of the production process which they were responsible on their own as they have to follow strict

[56] Marx, K. (1982). *Economic and philosophic manuscripts of 1844*. Translated by Martin Milligan. Moscow: Progress Publishers.
[57] Marx, K. (1982). *Economic and philosophic manuscripts of 1844*. Translated by Martin Milligan. Moscow: Progress Publishers, p. 30.
[58] Marx, K. (1982). *Economic and philosophic manuscripts of 1844*. Translated by Martin Milligan. Moscow: Progress Publishers, p. 28.

instructions and respect time limits. Taylorism and Fordism were exposed to extensive criticism for the boredom of their activities and the resulting mental disorders for workers.

However, the saturation of the mass market, the emergence of newly industrialized countries (which were characterised by low labour costs), the organisation of the petroleum exporting countries (OPEC) crises of 1973 and 1979, the market instability arising from the abolition of the fixed exchange rate regime and the growing dissatisfaction among people with regard to the alienation of human labour throw the model into crisis[59]. In turn, it became clear that it was necessary to switch to a new production method. "*It was only when computers, microelectronics, and telecommunications offered a new, technically reliable, and economically efficient mode of growth on a large scale that the new constellation could take over as the chief engine of growth*"[60].

1.3 The third industrial revolution

The third industrial revolution, also known as "digital revolution", took place following the Second World War (1945) and it caused deeper economic and social changes compared to previous industrial revolutions. It was characterized by the development of information and communications technologies (ICTs) which completely changed work organisation and people's lives. While the first machine age allowed the mankind to overcome the constraints of the physical world, the "*second machines age*"[61] changed the way people carry out mental work since they allowed for automating cognitive tasks too: "*computers and other digital advances are doing for mental power – the ability to use our brains to understand and shape*

[59] Freeman, C. and Louçã, F. (2001). As times goes by: from the industrial revolutions to the information revolution. New York: Oxford University Press, pp. 171-175.
[60] Freeman, C. and Louçã, F. (2001). As times goes by: from the industrial revolutions to the information revolution. New York: Oxford University Press, pp. 314.
[61] Brynjolfsson, E. and McAfee, A. (2014). *The second machine age*. 1st ed. New York: W. W. Norton & Company.

our environments – what the steam engine and its descendants did for muscle power. They are allowing us to blow past previous limitations and tacking us into new territory"[62]. During this period, there was a transition from the mass production to the lean production method also known as "Toyotism" (from the name of the Toyota car industry which was the first to adopt the new organisational method). The Toyota Production System is defined as "demand-pull" as opposed to traditional production methods (demand-push) since consumers determine the amount and the type of goods to be produced. The production process indeed is organised in such a way as to encourage adaption to market conditions. "*The basis of the Toyota Production System is the absolute elimination of waste. The two pillars that this is based on are just-in-time and autonomation, or automation with a human touch*"[63]. In particular, there are seven types of waste. They are listed below:

1. Waste due to over-production
2. Time-waste
3. Transportation (of useless material)
4. Waste from the non-use of new ideas
5. Waste of stock
6. Wastes occurring when defective products are created
7. Waste of movements

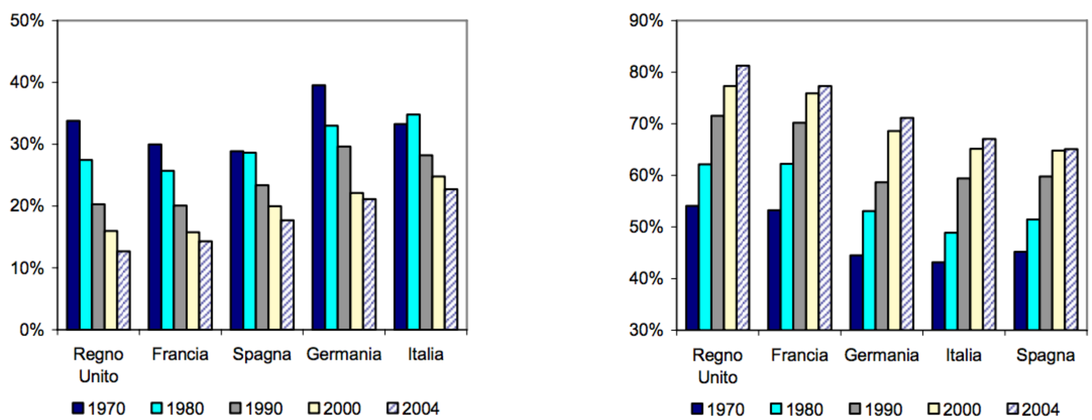
Just-in-time, which is a management technique aimed at eliminating the need to hold inventory, helps to remove these wastes. According to that methodology, materials are delivered just in time for them to be used in the production process or in a sale. Moreover, in order for the system to work properly, machines that can acknowledge any problem relating to defective products are needed. This will come about by making use of a "*device that could distinguish between normal and abnormal conditions*"[64]. The entire process is automated and, therefore, manpower is minimised: human supervision is not required unless

[62] Brynjolfsson, E. and McAfee, A. (2014). *The second machine age*. 1st ed. New York: W. W. Norton & Company, p. 8.
[63] Ohno, T. (1978). Toyota Production System: Beyond Large-Scale Production. Portland, Oregon: Productivity Press, p.4.
[64] Ohno, T. (1978). Toyota Production System: Beyond Large-Scale Production. Portland, Oregon: Productivity Press, p.7.

malfunctions of the equipment occur. All of this leads to cost-reduction and improved efficiency of the production process. Hierarchical levels are reduced, and greater participation in the production process is required from workers. Sometimes they are organized in work groups. Furthermore, all employees are encouraged to make proposals for improvements. It follows that the scientific management went against the de-skilling trend which had characterized the 19th century revolution: the new production method required high-skilled workers capable of working on their own. Employees had to supervise a number of machines and they were required to carry out maintenance operations. Then, greater competences were needed to perform these activities. Therefore, the digitalisation brought by the third industrial revolution was accompanied by an increase in the demand of skilled workforce. During the 18th century the skilled labour of craftsmen was replaced with machines operated by unskilled workforce. As a consequence of that, the demand for unskilled labour increase while that for high-skilled workers decreases, leading to a wage reduction for this category of workers. Contrary to what occurred in the past, the technological progress of the third industrial revolution was, instead, skill-biased: the labour demand for skilled people increased while the number of unskilled people employed in production processes decreased. In other words, "*the first technological advances reduced the relative demand for skilled labour but later advances increased it*"[65]. Low-skilled workers are more easily replaceable by machines than high-skilled ones. This is because they perform simple activities which can be easily automated: "*once the labour is simplified, the substitution of machines for labour becomes increasingly possible*"[66]. Technical progress, conversely, requires the contribution of workers who have the necessary skills to put machines into action. Therefore, technological progress acts as a substitute for unskilled labour while it is complementary to skilled workers. Another phenomenon that characterized period of the third industrial revolution was the emergence of the service economy also known as the "deindustrialization" process. This period, in fact, saw an increase in the number of people employed in the tertiary sector at the expense of the secondary

[65] Goldin, C., and Katz, L.F. (1998). "*The Origins of Technology-Skill Complementarity.*" The Quarterly Journal of Economics 113 (3).
[66] Braverman, H. (1998). *Labor and Monopoly Capital The Degradation of Work in the Twentieth Century*. New York: Monthly Review Press, p. 8.

(manufacturing) sector which become less significant both in terms of employment and gross domestic product (GDP). For example, in United Kingdom the share of employees in the manufacturing sector was 35% in 1970 and only 13% in 2004. Conversely, employment in the service sector went from 54% in 1970 to 80% in 2004[67]. All major economies were affected by a gradual restructuring of the manufacturing sector and by a parallel development of the service sector. This is represented in the figure below:



Figure[68]

On the y-axis is the percentage of people employed in the manufacturing sector (on the left) and the percentage of people employed in the service sector (on the right), on the x-axis is the countries. There are a number of explanations of the phenomenon. According to one line of thought, the more income per-capita increases the more the demand for services increases. Another explanation concerns the welfare state. The secondary sector became more capital-intensive, leading to a reduction of the human component employed in production processes. Then, the service sector would have absorbed the excess supply of labour to preventing

[67] Foresti, G., Guelpa, F. and Trenti, S. (2007). *La terziarizzazione dell'economia europea: è vera deindustrializzazione?*. Intesa SanPaolo collana ricerche.
[68] Foresti, G., Guelpa, F. and Trenti, S. (2007). *La terziarizzazione dell'economia europea: è vera deindustrializzazione?*. Intesa SanPaolo collana ricerche, p. 4.

political and social imbalances. Finally, the growth of the tertiary sector is related to liberalization of trade and the lower transport costs. This would have enabled companies to shift labour-intensive production activities towards countries where labour costs are cheaper. Developed countries, instead, would have focused on services to increase their competitiveness. These explanations are not mutually exclusive. Conversely, all of them contribute to explaining why the service sector grew at the expense of the manufacturing one. The service economy surely affected workforce composition, by increasing the level of competences required of the workforce. In fact, cognitive skills rather than manual ones were required in the performance of these activities.

Information and communications technologies (ICTs) favoured not only the development of a new production method but also the delocalization processes. Until that time, firms, while shipping products all over the world, conducted most of their production activities within the respective countries. But starting in the late 1970s, the global economy acquired a trans-national dimension. Production processes were broken up into different phases which were moved to foreign countries in order to exploit more favourable conditions and, therefore, to reduce production costs. When production activities are being coordinated at a global level, it is possible to talk about Global Value Chains: goods component may be produced and assembled in different locations while the final good may be shipped all over the world. The creation of the Global Value Chains (GVCs) was enabled by the globalization of the economy. The latter term refers to the phenomenon by which national markets became increasingly interconnected up to becoming part of a global system. The globalisation was made possible by two factors: the development of information and communications technologies (ICTs) which, in turn, allowed to reduce communication costs, and the improvement occurred in the transport sectors which enabled companies to ship products at great distance and low-cost.

The impact of information and communications technologies (ICTs) on productivity and employment will be analysed in the next chapter in more details.

Chapter 2: The ICTs revolution and labour market dynamics

2.1 The impact of technological progress on productivity

"*Western civilization has already witnessed three industrial revolutions, which could also be descripted as disruptive leaps in industrial processes resulting in significantly higher productivity. The first improved efficiency through the use of hydropower, the increasing use of steam power and the development of machine tools. The second brought electricity and mass production (assembly lines), and the third and most recent further accelerated automation using electronics and IT*"[69].

Every era of technological progress was defined by what can be called a general-purpose technology (GPT). The term refers to innovations that have the potential to speed up the economic progress. Like the steam engine and the electricity, computers fall into this category. General purposeness, continuous improvement, and the presence of innovation complementarities are the three main features of a general-purpose technology. First, these have to be versatile which means that they can be applied in all sectors of the economy. Second, they have to improve over time and their costs have to be reduced progressively. Third, general purpose technologies (GPTs) require the presence of innovational complementarities as "*technical advances in the GPT make it more profitable for its users to innovate, and vice versa*"[70].

Many believe that information and communication technologies (ICTs) possess these characteristics and, therefore, they should be considered as general-purpose technologies. First, computers' performance improves over time at an exponential rate. The Intel's co-founder and the pioneer of integrated circuits, Gordon Moore, was the one who first talked about the exponential growth of digital technologies. The following statement is remembered

[69] Acemoglu, D. and Restrepo, P. (2017). *Robots and Jobs: Evidence from US Labor Markets*. SSRN Electronic Journal, p. 2.

[70] Bresnahan, T. and Trajtenberg, M. (1995). *General purpose technologies 'Engines of growth'*?. Journal of Econometrics, 65(1), p. 4.

in history as Moore's law: "*the complexity for minimum component costs has increased at a rate of roughly of two per year*"[71]. In 1965, in fact, he predicted that the information and communications technologies' performance would be able to double on average every 12 months. Subsequently, he revised his forecast by upping it to 18 months. Secondly, almost every business uses computers in the performance of their activities and, as such, they exert a huge impact in many sectors of the economy. All this happens as a result of the combined application of computers and complementary innovations (namely information and communications technologies) which is the third prerequisite in order for computer to be described as a general-purpose technology (GPT).

If general purpose technologies should bring about and foster generalized productivity gains, why employment and productivity have been poor? The above question will be addressed in the following chapter.

It is structured as follows: in the first paragraph, by using Solow's exogenous growth model, we will show how long-term economic growth is determined by technological progress. Subsequently, we will analyse why the widespread diffusion of information and communications technologies did not led to economic growth, contrary to what was claimed by Solow. Then, employment impact of information and communications technologies (ICTs) will be discussed. If it is not possible to estimate whether technological progress creates or destroys jobs, many economists believe that changes in workforce composition are brought about by the introduction of new technologies into production processes. Therefore, two different hypotheses will be analysed in this connection, namely the skill-biased and the routine-biased technical change. We will close the chapter by analysing how information and communications (ICTs) technologies create earnings inequality.

[71] Moore, G. (1998). *Cramming More Components Onto Integrated Circuits*. Proceedings of the IEEE, 86(1).

2.1.1 The Productivity Paradox

Starting from the second half of the twentieth century, a noticeable acceleration of technological progress occurred. This has brought numerous questions on the consequences that the spread of *Information and Communications Technologies* (ICTs) will have on the economy and on the functioning of the labour market. Empirical research has tried, and it is still trying to answer these questions.

We can talk about technical progress when, through the use of new technologies, production processes are simplified and/or improved, new goods or services are created, or their characteristics are modified. Technical progress concerns both product and process innovation.

Shumpeter defined product innovation as "*the introduction of a new good (…) or a new quality of a good*"[72] and process innovation as "*the introduction of a new method of production (…) or a new way of handling a commodity commercially*"[73].

Through the use of technology, a company can produce the same output with less input, and, therefore, at a lower cost. The company, conversely, can decide to increase its production while maintaining total cost unchanged.

Robert Solow, a leading exponent of the neo-classical growth theory, by using the aggregate production function (that is related to the whole economic system and not to the individual company) shows that the neutral technological progress plays a decisive role in the economic growth of a country.

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[72] Schumpeter, J. A. (1934), Theory of Economic Development, Cambridge, Mass.: Harvard University Press.

[73] Schumpeter, J. A. (1934), Theory of Economic Development, Cambridge, Mass.: Harvard University Press.

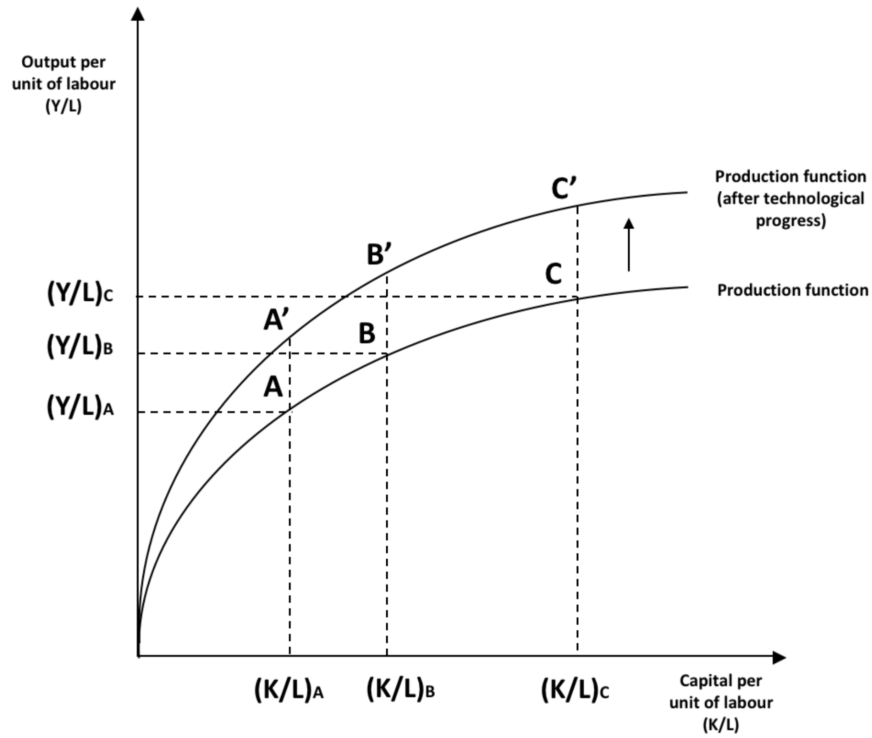

Figure [74]

The graph above compares the capital/work ratio (that is the average amount of capital available to each worker) with the amount of goods and services per worker. Inputs (capital and work) are characterized by constant returns to scale: doubling the amount of both inputs, the product is doubled. They are also characterized by diminishing returns. The law of diminishing returns, otherwise known as the "*law of variable proportions*"[75], was developed by the economist David Ricardo. According to that law, the addition of any further input (land, labour, capital, etc.) does not translate into a proportional increase of the output. By assuming that the share of employees remains constant over time, Solow identifies two sources of output growth: capital accumulation and technological progress.

[74] Blanchard, O., Amighini, A. and Giavazzi, F. (2011). *Macroeconomia: una prospettiva europea*. Bologna: Il mulino, p. 297.

[75] Ricardo, D. (1817). *On the principles of political economy and taxation*. London: John Murray

To find the source of economic growth, therefore, we should isolate the effects arising from an increase of capital accumulation from those deriving from technological progress. An increase of capital per worker results in a shift along the production function. Worker's marginal productivity and output increase as a result of capital accumulation. For example, the introduction of new machines in agriculture (which results in an increase of the capital/labour ratio) allows workers to be more productive, and, therefore, to produce greater amounts of product. However, because of the law of diminishing returns, by increasing the amount of capital per worker, output increases but at a decreasing rate. For example, moving from point A to point B, and from point B to point C, the output produced becomes increasingly smaller. Nevertheless, beyond a certain level (point C), the capital accumulation alone is no longer able to generate further output growth. The process of capital accumulation, in the absence of technological progress, reaches a point where no further increase is possible. It follows that capital accumulation alone is unable to drive economic growth.

Technological improvements, instead, move the whole production function upward. This makes it possible to generate a greater quantity of goods and services with the same amount of inputs (labour and capital). In this way, a potential product growth has been determined.

According to Solow, capital accumulation and technological progress are the only two factors that may lead to an increase of the output. If capital accumulation cannot drive economic growth forever, growth necessarily has to come from technological improvements. In other words, technological progress is a pre-requisite for achieving long-term and sustained growth.

Solow's economic growth model assumes that technological progress is an "*Hicks-neutral*" [76] factor. This means that "*shifts in the production function are pure scale change that leave marginal rates of substitution between factors untouched at given capital/labour ratios. In other words, technical change (...) for any given capital/labour ratio, proportionally increases total output*"[77]. Technical progress is, therefore, called total factor productivity augmenting.

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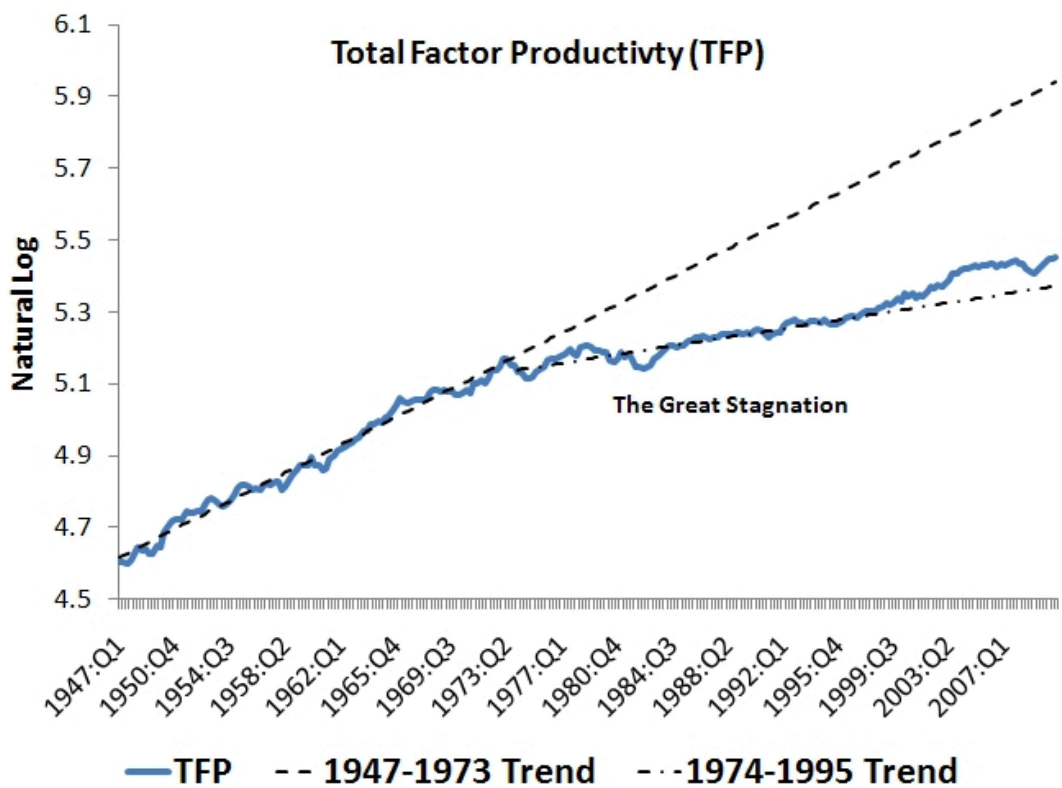
[76] Hicks, J. (1957). *The theory of wages*. Gloucester, Mass.: Peter Smith.
[77] Reati, A. (2001). *Total factor productivity – A misleading concept*. BNL Quarterly Review.

The total factor productivity (TFP), also known as multi-factor productivity, is a measure of economic efficiency and it is often considered the primary contributor to the economic growth rate. The technological progress of the first and the second industrial revolutions resulted in an increase of the total factor productivity (TFP) and, therefore, in economic growth, just as demonstrated by Solow. However, starting from the 1970s, the total factor productivity growth rate slowed down, as it is shown in the graph below.



Figure[78]

The graph above shows the fluctuation of the total factor productivity growth rate (TPF) during the period 1947-1995. On the X-axis is the period of time, and on the Y-axis is the total factor productivity (TPF) growth rate.

Total factor productivity (TPF) has grown significantly from 1947 to 1973, as can be seen in the graph above. However, its growth rate started to decrease from the 1970s.

[78] Beckworth, D. (2011). The Great Stagnation and Total Factor Productivity. [online] Macromarketmusings.blogspot.it. Available at: http://macromarketmusings.blogspot.it/2011/02/great-stagnation-and-total-factor.html [Accessed 4 May 2018].

The total factor productivity growth rate, in fact, increased significantly during the first industrial revolution which has been characterized by the advent of steam engine and the mechanical loom. Moreover, the growth rate speeded up during the second industrial revolution, due to the introduction of the internal combustion machine and of the electricity. The third industrial revolution, instead, has been characterized by a deceleration of the total factor productivity (TPF) growth rate. Therefore, the IT revolution has not resulted in economic growth.

The total factor productivity (TFP) index does not seem to be used very often in practice owing to the presence of a number of weaknesses.

First of all, it derives from a neoclassical production function which itself builds upon a series of unrealistic assumptions that are not always reflected in reality. Among these are the convexity and the perfect competition. First, information and communications technologies (ICTs) are characterized by increasing returns to scale: once the software is created, it can be endlessly replicated at little or no variable costs. This is contrary to the constant return to scale assumption on which the convexity of the production function depends. Secondly, the hypothesis of the perfect competition model is hard to find in today's economic reality which is increasingly characterized by companies' oligopolistic and monopolistic behaviours. If these assumptions no longer apply, it will not be possible to demonstrate Solow's residual and, therefore, how technical progress drives long-term growth[79]. Furthermore, the total factor productivity is not able to represent the key characteristics of the recent technological change. In fact, "*the term multifactor productivity identifies the portion of output growth left after accounting for growth in capital and labour. It is a catch-all for technological or organizational improvements that increase output for a given amount of input*".[80]

As it is evident from the statement above, the total factor productivity (TFP) represents the increase of the output which is not due to any increase in labour or capital. It is able to measure process innovations, organisational improvements, managerial skills, and gains in labour quality. "*These kinds of innovations, and possible external effects, certainly are*

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[79] Reati, A. (2001). *Total factor productivity – A misleading concept*. BNL Quarterly Review.

[80] Oliner, S. and Sichel, D. (2000). *The Resurgence of Growth in the Late 1990s: Is Information Technology the Story?*. SSRN Electronic Journal, p. 3.

relevant in the present period of structural change, but they are only a small part of the story. The most salient feature of such a change is that technical progress is first and foremost embodied in capital goods, and it is precisely because the workforce operates with improved machines that the enterprise benefits from an impressive increase in the productivity of labour".[81] Therefore, the total factor productivity index is not capable of capturing all the aspects of the recent technological revolution: it takes into account only the disembodied technological change, ignoring that incorporated into the inputs used in the production process.

Because the total factor productivity (TFP) index is far from perfect, other indices are used to measure economic performance. Among these, labour productivity is the most used. It can be defined as the amount of output produced for each hour worked. Contrary to the total factor productivity, the definition of labour productivity does not rely on a neoclassical production function and, therefore, it does not depend on unrealistic assumptions. Secondly, it "*encompasses all kinds of technical advances, since both embodied and disembodied technical changes have a direct effect on output and/or the quantity of labour*".[82] It is possible to divide labour productivity into two components to explain the concept better, as it is shown below.

$$\frac{Y}{L} \equiv \frac{K}{L} \frac{Y}{K}$$

Where:

- Y is the output
- L is labour
- K is capital

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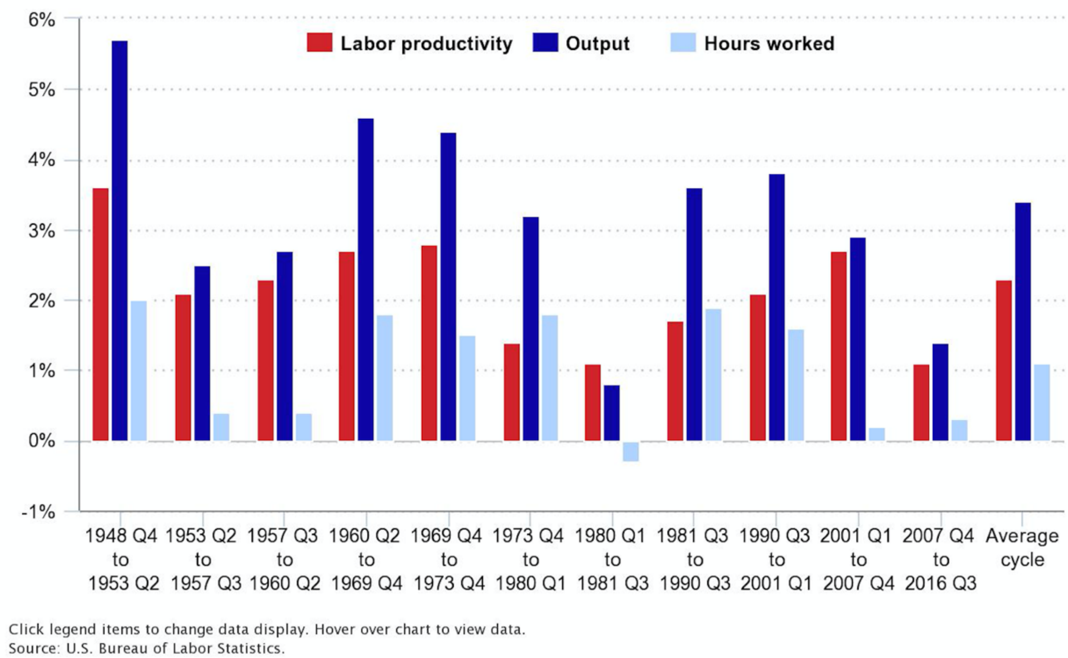
[81] Reati, A. (2001). *Total factor productivity – A misleading concept*. BNL Quarterly Review, p. 324.
[82] Reati, A. (2001). *Total factor productivity – A misleading concept*. BNL Quarterly Review, p. 326.

The first term refers to the degree of mechanization and it measures the technological change embodied in capital goods, whereas the ratio output/capital is considered to be a measure of the disembodied technological change. For all these reasons, labour productivity can be considered a better measure of technological change than total factor productivity. Therefore, for the purpose of completeness of our discussion, it is necessary to examine how the labour productivity growth rate evolved over time.



Figure[83]

The graph above shows growth rates of labour productivity, output, and hours worked for the nonfarm business sector over the period 1948-2016. On the y-axis is the percentage change in the annual growth rate, on the x-axis is the period of time. As can be seen from the chart above, "*the traditional productivity measure of output per hour slowed – dropping from a growth rate of 3.0 percent during the 1948-73 period to 0.8 percentage from 1973 to 1981. Of this 2.2 percentage point falloff, 0.3 percentage point was*

[83] Sprague, S. (2017). *Below trend: the U.S. productivity slowdown since the Great Recession*. Bureau of Labor Statistics, [online] 6(2). Available at: https://www.bls.gov/opub/btn/volume-6/below-trend-the-us-productivity-slowdown-since-the-great-recession.htm [Accessed 7 May 2018].

the result of the slowdown in the growth of capital per unit of labour input. The balance – that of multifactor productivity growth – reflected the remaining influences".[84]

Both labour and total factor productivity increased significantly until the 1970s. However, after this period, a significant downwards trend in terms of productivity took place. Indices have, in fact, documented a poor performance of productivity growth. The widespread diffusion of information and communications technologies should have led to an improvement of the various productivity indices. However, statistics showed a disappointing productivity trend compared to what occurred in the past.

This phenomenon has been called *"productivity paradox"*. As stated by the economist Robert M. Solow in 1987, "*we can see the computers everywhere except in the productivity statistics*"[85].

Some authors blamed information and communications technologies (ICTs) for the productivity slowdown. According to them, the technological improvements of the third industrial revolution could not be considered to be as important as those of ages past. The economist Robert J. Gordon claimed that *"the rapid progress made over the past 250 years could well turn out to be a unique episode in human history (…) I doubted that the 'new economy' would have an impact comparable to the invention of the second Industrial Revolution (...) Attention in the past decade has focused not on labour-saving innovation, but rather on a succession of entertainment and communications devices that do the same things as we could do before, but now in smaller and more convenient packages (…) These innovations were enthusiastically adopted, but they provided new opportunities for consumption on the job and in leisure rather than a continuation of the historical tradition of replacing human labour with machines"*[86]. According to Gordon, the information and communications technological revolution had not an important impact on people's working and living conditions compared to the technological innovations of the first and the second industrial revolution. Running water, electricity and internal combustion engine can be

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[84] Sprague, S. (2017). *Below trend: the U.S. productivity slowdown since the Great Recession*. Bureau of Labor Statistics, [online] 6(2). Available at: https://www.bls.gov/opub/btn/volume-6/below-trend-the-us-productivity-slowdown-since-the-great-recession.htm [Accessed 7 May 2018].

[85] Solow, R.M. (1987). *We'd Better Watch Out*. New York Times Book Review, p. 36.

[86] Gordon, R. (2012). *Is U.S. Economic growth over? Faltering innovation confronts the six headwinds*. NBER working papers, p. 15.

considered true epochal advances. Instant messaging and videogames, conversely, cannot have the same positive effect on productivity and standard of living.

Furthermore, the professor of George Mason University, Tayler, Cowen by observing the declining trend of the multifactor productivity over the period 1947-2011 come to the conclusion that we are suffering the consequences of slowing innovation. The latter, therefore, would be one of the factors responsible for the American recession and the lack of economic growth. In "The Great Stagnation" book, the author used the metaphor of the fruit to explain why economic growth slowed down in United States and in other advanced economies. Productivity gains are like fruits hanging from a tree which, in turn, is powered by innovations and new ideas (apart from free land and cheap labour force). Previous innovations made the tree green and, therefore, everyone was able to enjoy its fruits. For centuries, citizens have been doing nothing but reaching out their hand and reaping the benefits of a flourishing nature. In the last forty years, the availability of these fruits decreased due to the insufficient technological progress. Nowadays, in fact, *"we have failed to recognize that we are at a technological plateau and the trees are more bare than we would like to think*."[87] According to Cowen, innovations of the first and the second industrial revolution are certainly those that have most characterized our society and that have transformed people's lives (electricity, fertilizers, electric motors, cars, drugs, etc.). Nowadays, however, we are living in an age in which it seems difficult to generate innovations comparable to those of ages past. In Cowen's words: "*apart from the seemingly magical internet, life in broad material terms isn't so different from what it was in 1953*".[88] This caused the productivity slowdown.

Nevertheless, empirical data denied these pessimistic theses. In fact, since the 1990s, productivity has increased significantly.

Several authors attributed the underlying cause of the productivity resurgence to the Information and Communications Technologies (ICTs). In other words, they claimed that the production of information and communications technologies (ICTs) and their introduction in production processes led to an increase in productivity since the 1990s.

[87] Cowen, T. (2011). *The Great Stagnation*. Penguin Group US.
[88] Cowen, T. (2011). *The Great Stagnation*. Penguin Group US.

To assess the role that information and communications technology (ICT) played in the productivity growth, several studies have been carried out. This section gives a synthetic overview of the main finings.

Kevin J. Stiroh, the executive vice president of the Federal Reserve Bank of New York, conducted a study to examine whether productivity gains were concentrated in few industries or not, and, secondly, if they were associated with the IT-production and use. By using industry-level data, the author found that the U.S. productivity revival was a widespread phenomenon which affected various industries. "*These result raise doubts about the hypothesis that the recent productivity revival is due largely to gains in IT-producing industries (...) If gains were primarily due to the IT-production, the productivity revival would not appear broad-based*". [89] Moreover, through the use of several econometric tests, the author found that productivity gains were also linked to the IT-capital deepening: the more IT investments were made, the more productive industries were. Stiroh also analysed in which proportion IT-producing, IT-using, and the remaining industries (those that were isolated from the IT revolution) contributed to aggregate productivity growth. The data showed that the U.S. productivity revival was largely attributed to the production and the use of information and communications technologies (ICT). Therefore, in conclusion, IT-producing and IT-using industries were accountable for almost all the U.S. productivity revival whereas industries that were isolated from the IT revolution did not contribute to it. As is clear from the analysis, the productivity resurgence appeared to be related to IT.

A similar outcome comes from Dale Jorgenson and Kevin Stiroh's analysis. They used the U.S. National Income and Product Accounts (NIPA) data to examine the sources of the labour productivity growth over the period 1959-2003. There are three sources of labour productivity growth: capital deepening, gain in labour quality, and total factor productivity (TPF)."*Of the 1.57 percentage point increase in ALP growth after 1995, 0.86 percentage point was due to capital deepening and 0.80 percentage point due to faster TFP growth, with a small decline in labour quality growth of -0.09 percentage point. IT production accounted for more than 35 percent of the increase in*

[89] Stiroh, K. (2001). *Information Technology and the U.S. Productivity Revival: What do the Industry Data Say?*. SSRN Electronic Journal, p. 3.

aggregate TFP"[90].Technological progress has increased exponentially over the period in question, just as described by Moore's law. This led to an improvement of the efficiency of computer production and, therefore, to an increase in the total factor productivity (TFP) index. Moreover, the rapid technological advancements together with the IT capital declining prices have led companies to invest massively in IT assets, which resulted in an increase of both the capital deepening and the total factor productivity indices.
In conclusion, their analysis suggests that productivity gains came from both IT-producing and IT-using industries. In the authors' words: "*a consensus has emerged that a large portion of the acceleration through 2000 can be traced to the sectors of the economy that produce information technology or use IT equipment and software most intensively*"[91].
Furthermore, even the economists Stephen D. Oliner and Daniel E. Sichel emphasized the important role that information and communications technologies (ICTs) had on output and productivity growth. By using the Bureau of Economic Analysis (BEA) data and the Bureau of Labour Statistics (BLS) data, the authors found that while the output and productivity growth contribution arising from the use of computers' hardware and software was small prior to the 1990s, it increased significantly in the second half of the decade. In addition, they examined the growth contribution arising from the production of computer equipment (which includes both the production of semiconductors and of the computers themselves), pointing out that it led to an increase in the multifactor productivity (MFP) index. Their analysis concluded that IT has been a key factor behind the improved productivity performance of the American economy in recent years: *"The use of information technology and the production of computers accounted for about two-thirds of the 1 percentage point step up in productivity growth between the first and second halves of the decade"*[92].
Several reasons have been advanced to explain why productivity recovery happened twenty years after the introduction of computers in production processes.

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[90] Jorgenson, D., Ho, M. and Stiroh, K. (2004). *Will the U.S. Productivity Resurgence Continue?*. Federal Reserve Bank of New York, 10(13), p 3.
[91] Jorgenson, D., Ho, M. and Stiroh, K. (2004). *Will the U.S. Productivity Resurgence Continue?*. Federal Reserve Bank of New York, 10(13).
[92] Oliner, S. and Sichel, D. (2000). *The Resurgence of Growth in the Late 1990s: Is Information Technology the Story?*. SSRN Electronic Journal, p. 27.

Erik Brynjolfsson identified four possible explanations of the productivity paradox. A first *"explanation of the paradox is that the benefits from IT can take several years to show up on the bottom line (…) Because of its unusual complexity and novelty, firms and individual users of IT may require some experience before becoming proficient."*[93] Therefore, according to the author, it takes years for the productivity gains to emerge and that process depends significantly on the spread of complementary structures: new ways of organizing work are indeed needed to take advantage of new technologies. Paul David is of the same opinion: technologies may not have an immediate impact on the businesses' activities and, therefore, on the productivity of the economy. He cited the example of the introduction of electricity in the U.S. agricultural sector, whose benefits only developed after years, to prove his theory. The introduction of electricity into production processes, in fact, did not lead to an immediate rise in productivity. This is because electric motor was inserted in the same factory layout of the steam engine, which was not able to fully exploit its potential. It was only when the group drive system was replaced with the unit drive system that electricity was able to deliver benefits in terms of lower costs and improved quality of machine control. In fact, according to the author, *"the proximate source of the delay in the exploitation of the productivity improvement potential incipient in the dynamo revolution was, in large part, the slow pace of factory electrification. The latter, in turn, was attributable to the unprofitability of replacing still serviceable manufacturing plants embodying production technologies adapted to the old regime of mechanical power derived from water and steam".*[94] Therefore, it took years for electricity to develop productivity gains, since complementary organisational changes were needed to exploit the innovation's potential. According to Paul David, the same applies to computers: ICTs took their time to produce a significant impact on the economy. Like electricity, also ICTs belongs to the category of the general-purpose technologies (GPTs) which can be described as "*key functional components embodied in hardware that can be applied as elements or modular units of the engineering designs developed for a wide variety of specific*

[93] Brynjolfsson, E. (1993). *The productivity paradox of IT: review and assessment*. Communications of the ACM, p.12.
[94] David, P. (1990). *The Dynamo and the Computer: An Historical Perspective on the Modern Productivity Paradox*. The American Economic Review, 80(2), pp.355-361.

operations or processes". And like all the general-purpose technologies, they require the presence of innovation complementarities which would enable them to have full effect.

Brynjolfsson and Loring Hitt used firm-level data taken from 600 U.S. firms over the period 1987-1994 to examine the effects of computer on productivity and, therefore, to test the veracity of the "*diffusion lags*" hypothesis according to which innovations take a long time to produce tangible results. Their analysis showed that the contribution of computers on the productivity growth is the largest in the long-term. Data, in fact, showed that long-term productivity gains were five times greater than short-term productivity gains. These results *"are consistent with a story that the long-term growth contributions of computers represent the combination of computers and complementary organisational investment."*[95]

A second possible explanation of the productivity slowdown is that "*decision-makers aren't acting in the interest of the firm. Instead, they are increasing their slack, building inefficient systems, or simply using outdated criteria for decision making*".[96] Therefore, managers make decisions for themselves, without taking into account the interest of the company. This is known as the principal-agent or moral hazard problem and it occurs when managers put their personal interest before the interest of the company. Other times, they have not the necessary skills and knowledge to drive the technological transformation. All of this leads to the failure of the projects directly affecting the productivity of the investments.

According to the Brynjolfsson, another possible explanation of the productivity paradox is that technologies do not always expand the market but, conversely, they modify its composition by shifting market shares from one player to another one: "*IT may be beneficial to individual firms, but unproductive from the stand point of the industry as a whole or the economy as a whole: IT rearranges the shares of the pie without making it any bigger*".[97] For example, just think of what happened to Kodak. The important photo-industry went bankrupt because it was unable to seize the occasion that digital technologies could gave to the photographic sector. Although Kodak was the first to come up with a prototype of a digital

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[95] Brynjolfsson, E. and Hitt, L. (2003). *Computing Productivity: Firm-Level Evidence*. SSRN Electronic Journal.

[96] Brynjolfsson, E. (1993). *The productivity paradox of IT: review and assessment*. Communications of the ACM, p. 13.

[97] Brynjolfsson, E. (1993). *The productivity paradox of IT: review and assessment*. Communications of the ACM, p. 14.

camera, it chose to abandon this project because of the fear of competing with its own analogic products. Therefore, Kodak's fault has been to underestimate the disruptive strength of technological innovations, leading the photographic company to focus solely on its core business and to disregard the opportunities opened up by technological developments. Fujifilm, a Japanese photography company, instead, was able to exploit the technological progress and, therefore, to dominate the photographic market and even increase its market share at the expense of Kodak. Another recent example can be found in Netflix which has been one of the first companies to provide video on demand online. It was able to take advantage of the opportunity provided by Internet and to establish itself as one of the main players of the film distribution sector at the expense of Blockbuster, the famous video store company, which, conversely, was unable to keep up with technological progress. As stated by the Blockbuster CEO, Jim Keyes, in 2008: "*Neither RedBox nor Netflix are even on the radar screen in terms of competition (…) it's more Wal-Mart and Apple*".[98] Then, two years later, the DVD rental company claimed bankruptcy. The company went bankrupt for underestimating the digital delivery potential. Nowadays, Netflix, that made the online delivery its business, is worth 55 billion of euros. The latter has therefore been able to take over market shares from Blockbuster. The redistribution hypothesis shows that firms not investing in IT lose market shares which are otherwise gained by firms investing in IT. If the lost market shares are compensated by those gained through investments in IT, the effect of IT on productivity will be neutral. So, that may explain why productivity statistics were underestimated.

A last explanation of the productivity growth slowdown that occurred in the 1970s concerns the measurement problems associated with ICTs. "*Rapid innovation has made IT intensive industries particularly susceptible to the problems associated with measuring quality changes and valuing new products (…) Increased variety, improved timeliness of delivery and personalized customer service are additional benefits that are poorly represented in productivity statistics. These are all qualities that are particularly likely to be enhanced by*

[98] Munarriz, R. (2008). *Blockbuster CEO Has Answers*. [online] The Motley Fool. Available at: https://www.fool.com/investing/general/2008/12/10/blockbuster-ceo-has-answers.aspx [Accessed 12 May 2018].

IT".[99] Computers, in fact, enable companies to produce different products variants and to improve the quality of their goods. These aspects are hard to measure through official statistics because of the difficulty to assess the real value of the goods' quality and/or variety, especially if comparators are not available. Furthermore, in contrast to tangible goods, it is not easy to quantify the IT stock used in the production processes, because of their intangible nature.

Another measurement problem is related to the fact that the gross domestic product (GDP) takes into account only monetary transactions and, therefore, it ignores all those free of charge. Clearly, digital goods, which are characterized by zero marginal costs of production and non-rivalry in consumption, are understated by productivity measures: these goods have a big impact on people's life, but they are not represented in productivity statistics because they are produced and consumed for free. Whereas the production of a car requires considerable investments, either fixed and variables, the production of a software does not entail high costs. An initial investment in infrastructure (such as computers and programmers) is required. However, after the first unit of the software is produced, it can be reproduced and spread endlessly at little or no variable expenses. Furthermore, when the software is uploaded on a site, millions of users can download it at no cost. For example, consider apps like Skype, WhatsApp, or Telegram which enables millions of users to communicate, chat, and talk on the phone for free without incurring costs of telephony. All this does not allow to quantify the real contribution of information and communications technologies (ICTs) to productivity. Therefore, measurement errors could be the cause of the productivity slowdown. Measurement problems are particularly acute for service industries, which own most of the IT capital.

Nowadays, the debate on the contribution of information and communications technologies (ICTs) to productivity has been reopened. This is because, the U.S. productivity growth rate has slowed down, despite the introduction of the technologies of Industry 4.0. The U.S. labour productivity, in fact, increased by 3.3% over the period 1996-2003; however, currently, the annual rate of labour productivity growth has declined, reaching 1.5% in 2015.

[99] Brynjolfsson, E. (1993). *The productivity paradox of IT: review and assessment*. Communications of the ACM, p. 10.

According to the data taken from the National Institute of Statistics (ISTAT), the Italian labour productivity decreased from 1% in 2009 to 0,3% in 2015 whereas the total factor productivity decreased from 0,78% in 2009 to 0,4% in 2015. The introduction of these new technologies should have led to a consequent increase in productivity, as happened in the past. Productivity growth, on the other hand, has been constantly slow.

It is probably too early to see the benefits produced by the introduction of the technologies of Industry 4.0 into production processes. Perhaps, these will have their full impact in the near future. Nowadays, however, we cannot draw any general conclusion regarding whether new technologies will lead to productivity growth or not. Beyond the different points of view, several studies have provided empirical evidence in support of the important role of ICTs on economic growth and confirmed their positive effects on productivity. As stated by Paul David, just like the introduction of electricity in the factory system did not lead to the end of the growth, also digital technologies had no detrimental impact on the businesses' productivity. Therefore, this might also apply in the case of the 21-st century technologies.

Several consulting societies have drawn up optimistic estimations relative to the capacity of the technologies of Industry 4.0 to boost productivity. They estimated that productivity will raise by as much as 2-3% in the foreseeable future. The McKinsey Global Institute, to name a few, is confident that new technologies will lead to productivity growth despite some may think that these will not have the same impact that the previous innovations have had: "*Some economists question whether technology can still deliver the kind of wide-ranging, profound impact that the introduction of the automobile or the semiconductor chip had, and point to data showing slowing productivity growth in the United States and the United Kingdom – often early adopters of new technology – as evidence. While we agree that significant challenges lie ahead, we also see considerable reason for optimism about the potential for new and emerging technologies to raise productivity and provide widespread benefits across economies*".[100] McKinsey's study, in fact, provides that the digitalization of production processes will result in an annual rate of increase in productivity of 0.8 to 1.4%.

[100] Manyika, J., Chui, M., Bughin, J., Dobbs, R., Bisson, P. and Marrs, A. (2013). *Disruptive technologies: Advances that will transform life, business, and the global economy*. McKinsey Global Institute Report.

2.2 The impact of technological progress on employment levels

The introduction of new technologies in production processes has been widely analysed in the previous paragraph with regard to its positive impact on economic growth. However, the effects that it might have on labour market are less clear cut and indeed subject of some dispute. Economists have always wondered about the effects of technology in terms of employment. Some argue that the introduction of technological innovations in production processes has a negative effect since it involves the substitution of human labour by machines. Others, however, consider the substitution effect a short-term phenomenon. Over time, the market mechanisms will lead to the development of new productive sectors and, therefore, new job opportunities could be created.

"*In short, technological progress has two competing effects on employment. First, as technology substitutes for labour, there is a destruction effect, requiring workers to reallocate their labour supply; and, second, there is the capitalisation effect, as more companies enter industries where productivity is relatively high, leading employment in those industries to expand"*[101].

Even today, the problem of the potentially negative impact of technological progress on employment is the subject of studies and analysis.

One of the first forms of protest against the introduction of new machines into production processes is represented by the luddism. It is a workers' protest movement that has developed in England during the nineteenth century. Between 1811 and 1817 some British weavers attacked the mechanical looms introduced during the first industrial revolution because of the fear that these industrial machines could stole their jobs. The machines, in fact, were viewed as a threat to workers' employment and, therefore, they were considered responsible for low wages and unemployment.

[101] Frey, C. and Osborne, M. (2013). *The future of employment: How susceptible are jobs to computerisation?*. Technological Forecasting and Social Change, 114, pp 13.

Several economists have analysed the phenomenon of unemployment generated by the introduction of technologies into production processes.

The term "*technological unemployment*" first appeared in Keynes' "*Economic Possibilities for our Grandchildren*"[102] chapter:

"*We are being afflicted with a new disease of which some readers may not have heard the name, but of which they will hear a great deal in the years to come – namely, technological unemployment. This means unemployment due to our discovery of means of economizing the use of labour outrunning the peace at which we can find new uses for labour*"[103].

In 1983, the American economist and Nobel Prize Leontief claimed that machines would replace human labour just like the tractor replaced the horse: "*Computers and robots replace humans in the exercise of mental functions in the same way as mechanical power replaced them in the performance of physical tasks. As time goes on, more and more complex mental functions will be performed by machines. Any worker who now performs his task by following specific instructions can, in principle, be replaced by a machine. This means that the role of humans as the most important factor of production is bound to diminish—in the same way that the role of horses in agricultural production was first diminished and then eliminated by the introduction of tractors*" [104].

Actually, what was claimed by these economists has not occurred since, from the beginning of the industrial era, there has been a simultaneous increase in productivity and employment. The history of mankind has been affected by millennia of technological progress: starting with the first agricultural technologies and the machines of the industrial revolution, up to the most recent diffusion of personal computers and digitization. Despite the numerous and profound changes brought about by technology, the total number of jobs has always increased, leaving aside periodic economic crises.

To quote the Boston Consulting Group: "*Industrial production was transformed by the steam power in the nineteenth century, electricity in the early twentieth century, and automation in the 1970s. These waves of technological advancement did not reduce overall employment,*

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[102] Keynes, J. (1931). *Essays in persuasion*. London: Macmillan, pp.321-334.

[103] Keynes, J. (1931). *Essays in persuasion*. London: Macmillan, pp.321-334.

[104] National Research Council (1983). *The Long-Term Impact of Technology on Employment and Unemployment*. Washington, DC: The National Academies Press, p.3.

however. Although the number of manufacturing jobs decreased, new jobs emerged and the demand for new skills grew". [105]

The production processes, through the adoption of new technologies, have become more efficient and, therefore, they have enabled sales prices reductions. As a result of that, the demand for goods increased and new jobs were created. Technological progress has increased not only people's purchasing power but also it resulted in the creation of new jobs. In other words, employment has benefited, either directly or indirectly, from technological innovations. The economists of the National Academy of Sciences came to the same conclusion: technological progress creates jobs instead of destroying them. The report "*Technology and Employment: Innovation and Growth in the U.S. Economy*"[106] suggests that, on one hand, technological progress reduces the amount of work and other resources needed to produce a unit of output; on the other hand, it creates greater prosperity without, at the same time, reducing employment:

"*By reducing the costs of production and thereby lowering the price of a particular good in a competitive market, technological change in production processes frequently leads to increased demand for that good; greater output demand results in increased production, which requires more labour, and offsets the effects of reductions in the amount of labour required per unit of labour. Even if the demand for a good whose production process has been transformed does not increase significantly when the price of the good is lowered, benefits still accrue because consumers can use the savings from price reductions to purchase other goods and services. In the aggregate, therefore, employment often expands. Moreover, when technological change results in the development and production of new products, employment grows in the industries that serve the markets for these goods, as well as in the industries supplying inputs to them*".[107]

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105 Lorenz, M., Rüßmann, M., Strack, R., Lueth, K. and Bolle, M. (2015). *Man and Machine in Industry 4.0 How Will Technology Transform the Industrial Workforce Through 2025*?. Boston Consulting Group.

106 Cyert, R. and Mowery, D.C. (1987). *Technology and Employment: Innovation and Growth in the U.S. Economy*. Washington, D.C.: National Academy Press.

107 Cyert, R. and Mowery, D.C. (1987). *Technology and Employment: Innovation and Growth in the U.S. Economy*. Washington, D.C.: National Academy Press.

The theory according to which the compensation effect prevailed, over the long term, on the substitution effect following the introduction of machines in the production processes, showed empirical evidence.

Deloitte's study should be mentioned in this respect. The Deloitte's economists cross-referenced employment trends in England and Wales with the various technological inventions developed over the period 1871 to 2001. This study found that technology did not destroy certain jobs, but, instead, it was "*a great job-creating machine"*[108]. In fact, technology contributed to the development of new economic sectors. Moreover, it led to an increase in employment in sectors with a strong human component, such as those of baristas and hairdressers. This has made it possible to offset the loss of jobs in sectors where human labour is more easily replaceable by machines:

"The dominant trend is the contracting of employment in agriculture and manufacturing being more than offset by rapid growth in the caring, creative, technology and business services sectors (…) Machines will take on more repetitive and laborious tasks but seem no closer to eliminating the need for human labour than at any time in the last 150 years".[109]

During the period considered, agricultural employment fell by 95% whereas the laundry sector saw the number of its jobs drop by the 83%. However, the demand for jobs increased by 909% in the health sector and by 508% in the education sector over the last twenty years. The increased employment in these sectors has offset the loss of jobs in sectors based on "muscle strength". Moreover, Deloitte's economists claimed that the increased employment enhanced purchasing power. This led people to increase their spending on services related to personal care. In fact, the number of barbers and hairdressers quadrupled.

Recently, the debate about "*technological unemployment*"[110] has been reopened as a result of the downward employment trend that occurred in some advanced economies, especially in the United States of America.

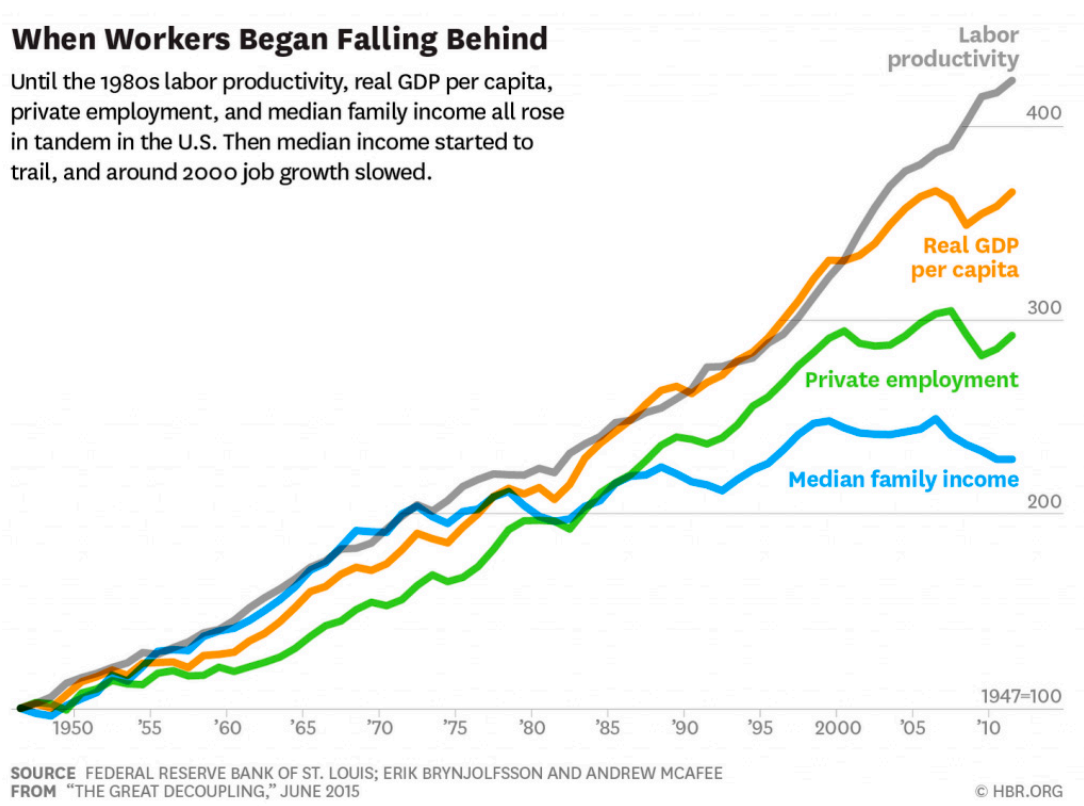
Many believe that the technological advancements of the third industrial revolution have had a potentially negative impact on employment levels. This, of course, raised the question:

[108] Deloitte (2015). *Technology and people: The great job-creating machine.* Deloitte LLP, p. 5.
[109] Deloitte (2015). *Technology and people: The great job-creating machine.* Deloitte LLP, p. 4.
[110] Keynes, J. (1931). *Essays in persuasion*. London: Macmillan, pp.321-334.

Does technology create or destroy jobs? The answer is neither easy nor unambiguous. Both answers are plausible.

The two Massachusetts Institute of Technology scholars, Erik Brynjolfsson and Andrew McAfee, conducted a study to analyze the relationship between technological change, employment, and wage levels over the period 1947-2010. According to the authors, employment and wages growth has been matched by an increase in productivity, at first. During recent years, "*the great decoupling*"[111] emerged as a new phenomenon affecting the economy: productivity increased while employment and wages declined.

The chart below was drawn using the Federal Reserve Bank data. It shows the trends of productivity (in grey), employment (in green), GDP (in orange), and the average income (in blue) over the period 1947-2010.



[111] Bernstein, A. and Raman, A. (2015). *The Great Decoupling: An Interview with Erik Brynjolfsson and Andrew McAfee*. Harvard Business Review. [online] Available at: https://hbr.org/2015/06/the-great-decoupling [Accessed 3 May 2018].

Figure[112]

The curves followed the same trend until the end of the last century: employment and wages increased in step with productivity. Since 2000, the lines have diverged: while productivity continued to increase exponentially, employment and wages declined. In other words, over the past decade, employment and wages have stopped following productivity. The gap between economic growth and job creation is not only a theoretical fact of the current economy but also an empirical one. The two authors attribute the cause of the decoupling to the recent technological advances. Technological progress would have destroyed jobs faster than creating them, as they said. While the first machines had replaced workers in carrying out manual tasks, nowadays, new technologies are progressively replacing humans in carrying out cognitive works too. In other words, machines are entering domains that were considered to be wholly owned by men. According to the authors, the technological acceleration will lead to productivity growth, while, simultaneously, destroying many jobs. This will create a large gap between those who will benefit from technical progress and those who will remain excluded.

Even the economist Jeremy Rifkin, in his book "*End of work*"[113], predicted that the twenty-first century would be characterized by mass unemployment. Technological progress would lead to the replacement of human labour with machines which are becoming increasingly intelligent and autonomous, as the author claimed. In his opinion: "*we are entering a new phase in the world history – one in which fewer and fewer workers will be needed to produce the goods and services for the global population (…) In the years ahead, more sophisticated software technologies are going to bring civilization ever closer to a near-workerless world*

[112] Bernstein, A. and Raman, A. (2015). *The Great Decoupling: An Interview with Erik Brynjolfsson and Andrew McAfee*. Harvard Business Review. [online] Available at: https://hbr.org/2015/06/the-great-decoupling [Accessed 3 May 2018].

[113] Rifkin, J. (1995). *The End of Work: The Decline of the Global Labor Force and the Dawn of the Post-Market Era*. Putnam Publishing Group.

(…) Today, all sectors of the economy (…) are experiencing technological displacement, forcing millions onto the unemployment roles".[114]

All the previous mentioned authors see technological progress as one of the causes of structural or long-term unemployment. In the light of the above, we can really question whether the introduction of new technologies is responsible for the employment stagnation of the recent decades. Many labour economists argue that it is not possible to draw any definitive conclusion. The causes of the stagnation might be different. These could, for instance, include the globalization of markets and the financial crises.

As regard the effects of new technologies on employment levels, two opposing currents of thought can be identified. On one hand, the techno-pessimists like Rifkin, Brynjolfsson, and McAfee argue that technology leads to unemployment. On the other hand, the techno-optimists state that workers replaced by machines will find another job. While accepting that technological progress can lead to the loss of jobs over the short term, they foresee that new ones will be created through the compensation effect over the long term.

Several authors have tried to estimate the impact of technologies on labour market. The effects on employment in quantitative terms have been evaluated at the firm-, industry-, and at the macroeconomic level, and also through simulation studies. The following table summarizes the main findings:

Study	Countries	Years	Level of analysis	Innovation data sources	Results on employment
Firm level studies					
Machin and Wadhwani, 1991	UK	1984	Cross firm, manufacturing	British workplace industrial	Positive

[114] Rifkin, J. (1995). *The End of Work: The Decline of the Global Labor Force and the Dawn of the Post-Market Era.* Putnam Publishing Group.

				relations survey	
Brouwer, Kleinknecht and Reijnen, 1993	Netherlans	1983-8	Cross firm, manufacturing	Dutch survey	Negative Positive with product innovation
Meghir, Ryan and Van Reeenen, 1996	UK	1976-82	Panel of firms, manufacturing	SPRU Innovation database and patents	Positive with more flexibility
Van Reenen, 1997	UK	1976-82	Panel of manufacturing firms	Survey on UK firms	Positive
Smolny, 1998	Germany	1980-92	Panel of manufacturing firms	Survey on German firms	Positive
Greenan and Guellec, 2000	France	1986-90	Cross firm, manufacturing Cross sector	Innovation survey	Positive at the firm level Negative at the industry level for process innovation
Industry-level studies					
Meyer-Kramer, 1992	Germany	1980s	Input Output Model of all economy	Industry data	Negative differentiated by sector

Vivarelli, Evangelista and Pianta, 1996	Italy	1985	Cross sector 30 manufacturing industries	Innovation survey	Negative of process innovation Positive of product innovation
Pianta, 2000	5 EU countries	1989-93	Cross sector 21 manufacturing industries	Innovation survey	Overall negative Positive of product innovation
Antonucci and Pianta, 2002	5 EU countries	1994-9	Cross sector 19 manufacturing industries	Innovation survey	Overall negative Positive of product innovation
Evangelista and Savona, 2002	Italy	1993-5	Cross sector services industries	Innovation survey	Overall negative Differentiated by service industries and size
Macroeconomic-level studies					
Layard and Nickel, 1985	UK	1954-83	Macro model	Labour productivity	Neutral
Vivarelli, 1995	US and Italy	1966-86	Macro model	R&D linked to product	Differentiated by compensation

				and process innovations	mechanism and country
Simonetti, Taylor and Vivarelli, 2000	US, Italy, France, Japan	1965-93	Macro model	R&D linked to product and process innovations	Differentiated by compensation mechanism
Simonetti and Tancioni, 2002	UK and Italy	1970-98	Macro model quarterly data	R&D linked to product and process innovations	Differentiated by compensation mechanism
Simulation studies					
Leontief and Duchin	US	1980-2000	Input output model all economy	Assumptions on performance	Negative
Kalmbach and Kurz	Germany	2000	Input output model all economy	Assumptions	Negative
IPTS-ESTO 2001	Europe	2000-2020	General equilibrium model all economy	Assumptions on productivity growth	Positive, differentiated by innovation policy

Figure[115]

"*The evidence on the overall employment impact of innovation at the level of firms tends to be positive: firms that innovate in products, and also in processes, grow faster and are more*

[115] Pianta, M. (2006). *Innovation and employment*. In: J. Fagerberg, D. Mowery and R. Nelson, ed., The Oxford Handbook of Innovation. [online] Oxford University Press, pp.568-597. Available at: https://works.bepress.com/mario_pianta/31/ [Accessed 3 May 2018].

likely to expand their employment than non-innovative ones, regardless of industry, size, or other characteristics". [116]

Firm-level analysis are based on sample data concerning national manufacturing sectors. Panels are not representative of the whole manufacturing industry. Moreover, they do not take into account the services sector. Therefore, these studies do not consider all firms that could be either created or destroyed by technological progress. As a result of that, it is difficult to draw any general conclusions about the economy as a whole. To overcome these limitations, scholars have conducted industry-level analysis. In this way, both the direct firm-level consequences and the indirect effects occurring within the industry are being considered.

Industry-level studies lead to a different outcome than firm-level analysis. They show that product and process innovation have two opposite effects on employment levels. On one hand, product innovation has a positive effect on employment in a context of increasing demand. "*High demand growth leaves room for a variety of firm strategies and for better employment outcomes, while stagnant demand deepens the selection process among firms and emphasizes the role of technological competition*".[117] On the other hand, process innovation leads to job losses since it reduces labour demand by increasing productivity.

The macroeconomic-level analysis provides the most comprehensive understanding of the impact of technologies on employment levels. Macroeconomic studies, in fact, take into account a multitude of the indirect effects technology can have on the economic system as a whole. Therefore, they may lead to different results from those above-mentioned: "*the overall findings of these studies point to a differentiated impact of innovation depending on countries' macroeconomic conditions and institutional factors. The employment impacts of innovation generally are more positive in economies in which new product generation and investment in new economic activities are higher, and in which the demand-increasing effects*

[116] Pianta, M. (2006). *Innovation and employment*. In: J. Fagerberg, D. Mowery and R. Nelson, ed., The Oxford Handbook of Innovation. [online] Oxford University Press, p. 576. Available at: https://works.bepress.com/mario_pianta/31/ [Accessed 3 May 2018].

[117] Pianta, M. (2006). *Innovation and employment*. In: J. Fagerberg, D. Mowery and R. Nelson, ed., The Oxford Handbook of Innovation. [online] Oxford University Press, p. 579. Available at: https://works.bepress.com/mario_pianta/31/ [Accessed 3 May 2018].

of price reductions are greater".[118] Macroeconomic-level studies take into consideration the indirect effects arising from the "compensation mechanism". The theory that market mechanisms will lead to the creation of new jobs over the long term, by offsetting all those lost as a result of the introduction of technological innovations into production processes, is known since the times of David Ricardo and Karl Marx.

A study conducted by Vivarelli (1995) analysed the relationship between process innovation and unemployment, finding six market mechanism that can outweigh the negative effects of technology on employment. The most important of these is the compensation mechanism via decrease in prices: technological process leads to price reductions and, therefore, it increases people purchase power. In turn, an increase in consumption will also increase the demand for new goods and services, leading to the creation of new productive sectors and job opportunities.

However, even the macroeconomic-level analysis has its limitations. The problematic issues are to construct an appropriate model and to find suitable data. Finally, the relationship between innovation and employment has been studied through the use of simulation, as shown in the table above. However, even this approach is far from perfect. Simulations based on the general equilibrium model are not able to identify technological unemployment whereas those based on the input-output model do not account for the compensation mechanism.

The results of simulations carried out show that *"both sectoral and aggregate studies generally point out the possibility of technological unemployment, which emerges when industries or countries see the prevalence of process innovations in contexts of weak demand. Firms innovation in both products and processes may be successful in expanding output and jobs regardless of the economic context, but often do so at the expense of non-innovating firms. The specificities of industries, countries, and macroeconomic conditions are crucial*

[118] Pianta, M. (2006). *Innovation and employment*. In: J. Fagerberg, D. Mowery and R. Nelson, ed., The Oxford Handbook of Innovation. [online] Oxford University Press, p. Available at: https://works.bepress.com/mario_pianta/31/ [Accessed 3 May 2018].

determinants of the results obtained in empirical studies"[119]. All studies available are based on national economies data. Therefore, no analysis has analysed the issue of the impact of innovation on employment levels in a global dimension this far.

In conclusion, the data available do not make it possible to determine with certainty whether the introduction of new technologies in production processes resulted in an increase or decrease of the employment levels.

2.3 The impact of technological progress on workforce composition

As has been shown by many studies already carried out, the impact of technological innovations on employment levels is unclear. Researches deliver contradictory results. Some argue that the introduction of new technologies into production processes leads to employment reduction due to the substitution effect. Others claim that new jobs will be created over the long term through the compensation effect. Nevertheless, studies and results of the researches relating to the consequences of technical progress on workforce composition came to the same conclusion. It is generally accepted that the introduction of digital technologies initially favoured high-skill workers, while replacing less-skilled ones. This phenomenon is known as skill-biased technological change.

Starting from the 90s, however, medium-skilled employment declined. At the same time, employment for both high-skilled and low-skilled workers grew. This resulted in a polarization of the labour market.

The task model developed by Autor et al (2003) can be used to explain how technological progress affected workforce composition. The model distinguishes between routine and non-routine activities. Moreover, these can be distinguished in manual and cognitive tasks. According to Autor et al (2003), digitization replaces medium-skill workers who perform

[119] Pianta, M. (2006). *Innovation and employment*. In: J. Fagerberg, D. Mowery and R. Nelson, ed., The Oxford Handbook of Innovation. [online] Oxford University Press, p. 583. Available at: https://works.bepress.com/mario_pianta/31/ [Accessed 3 May 2018].

routine activities. However, technological progress is complementary to workers who perform non-routine activities.
The phenomenon of labour demand-side shift towards non-routine activities arising from the introduction of technologies into production processes is known as task-biased technical change or routine-biased technical change (RBTC).
The two different phenomena will be analysed in the following paragraphs.

2.3.1 Skill-biased technical change

According to the neoclassical economist Robert Solow, technological progress is the main factor determining an increase in per-capita income. To explain how the introduction of new technologies into production processes drives economic growth, he uses a model in which technological progress is considered a neutral factor given that it influences inputs in equal measure: *"shifts in the production function are defined as neutral if they leave marginal rates of substitution untouched but simply increase or decrease the output attainable from given inputs."* [120] However, technology does not always influence inputs in equal measure. It can also be biased towards some factors.
Many economists believe that the wage inequality that occurred in the United States during the second half of the twentieth century was mainly caused by the introduction of the new digital technologies into production processes. By observing American wage developments over the period 1950-2000, scholars, in fact, assumed that technology was not skill-neutral. They thought, conversely, that technology was skill-biased. The latter would have provided positive profit contribution to high-skilled workers compared to less-skilled ones. In other words, technological progress seemed to have benefited workers with a high level of education compared to those who were less educated. This hypothesis is known as skill-biased technical change. G. Violante wrote in his paper: *"Skill biased technical change is a shift in the production technology that favours skilled (e.g., more educated, more able, more*

[120] Solow, R.M. (2018). *Technical Change and The Aggregate Production Function.* The Review of Economics and Statistics, 39(3), pp.312-320.

experienced) labour over unskilled labour by increasing its relative productivity and, therefore, its relative demand. Ceteribus paribus, SBTC induces a rise in the skill premium – the ratio of skilled to unskilled wages."[121]

Low-skilled workers are more easily replaceable by machines than high-skilled ones. This is because they perform simple activities which can be easily automated. Technical progress, conversely, requires the contribution of workers who have the necessary skills to put machines into action. To quote Greenwood and Yorkoglu: *"setting up, and operating, new technologies often involves acquiring and processing information. Skill facilitates this adoption process".*[122] Therefore, according to the skill-biased technical change hypothesis, technological progress increases the demand for high-skilled labour while, at the same time, it decreases the demand for unskilled labour. As a result of that, high-skilled workers' wages will increase. Less skilled workers' wages will decrease. The negative wage gap between high-skilled and low-skilled workers widened considerably over the period 1950-2000. At the same time, the number of people enrolled in college increased. Consequently, a simultaneous increase in the supply and in the wages of skilled workers occurred.

This trend has been analysed by several scholars. For example, the data collected by David Autor, Lawrence Katz and Alan Krueger show that "*the log college/high school wage differential has grown substantially (by 0.25) since 1950 with a more than threefold increase in the employment share of college graduates*". [123]

However, according to the law of supply and demand, as labour supply increases, wages should fall. To explain how wages vary in relation to the number of people employed, we can use the underlying scheme taken from the Acemoglu's *"Technical change, Inequality and Labor Market"*[124] paper.

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[121] Violante, G. (2008*). Skill-Biased Technical Change*. In: S. Durlauf and L. Blume, ed., The New Palgrave Dictionary of Economics, 2nd ed. Palgrave Macmillan.
[122] Greenwood, J., Yorukoglu, M. (1997). Carnegie-Rochester conference series on public policy, 46:North–Holland, p.87
[123] Autor, D., Katz, L. and Krueger, A. (1998). *Computing Inequality: Have Computers Changed the Labor Market*?. The Quarterly Journal of Economics, 113(4), pp.1169-1213.
[124] Autor, D., Katz, L. and Krueger, A. (1998). *Computing Inequality: Have Computers Changed the Labor Market*?. The Quarterly Journal of Economics, 113(4), pp.1169-1213.

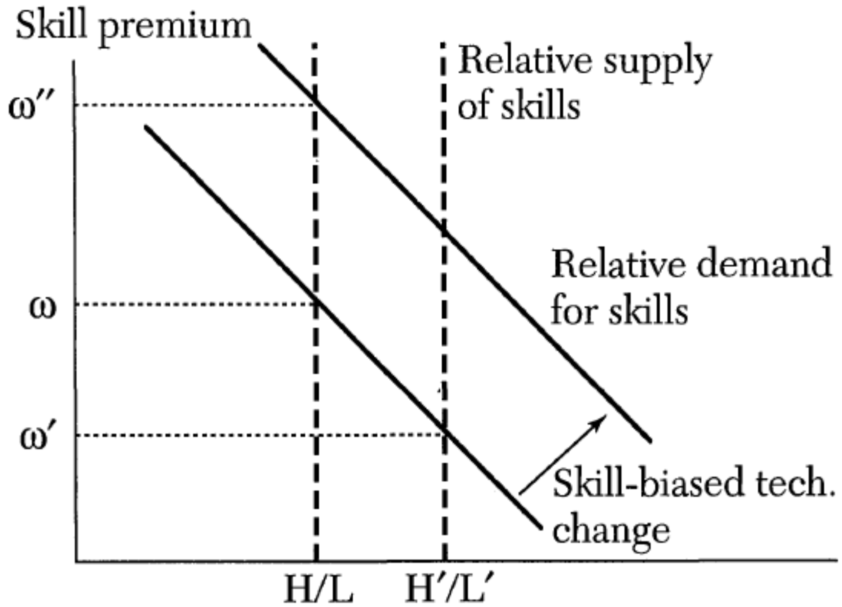

Figure [125]

Along the y-axis, we have the ratio between skilled and unskilled workers' wages, and along the x-axis, we have workers' relative supply. As the figure shows*, "an increase in the relative supply, from H/L to H'/L', moves the equilibrium point along the downward sloping relative demand curve, and reduces the skill premium from w to w''*'.[126] Here, the skill premium represents the ratio of skilled workers' wages to unskilled workers.

During the seventies, to the increased high-skilled workers' supply has not been followed by a decrease in the skill-premium. To fulfil this condition, it is necessary that the demand for skilled labour grows faster than the supply. Only in this way it will be possible to avoid the skilled workers' wages reduction. In other words, the simultaneous increase in the supply and in the wages of skilled workers can only mean that the demand for skilled labour has increased much more than the supply.

This is the conclusion reached in Acemoglu's paper. Furthermore, the author argues that technological change was the fundamental cause of the demand-side shift. According to the economist, technological change has been skill-biased and, therefore, it has

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[125] Acemoglu, D. (2002). *Technical Change, Inequality, and the Labor Market*. Journal of Economic Literature, 40(1), p. 20.

[126] Autor, D., Katz, L. and Krueger, A. (1998). *Computing Inequality: Have Computers Changed the Labor Market*?. The Quarterly Journal of Economics, 113(4), pp.1169-1213.

favoured those in possession of more education. Conversely, technological innovations replaced unskilled workers in carrying out repetitive tasks. As stated by Acemoglu e Autor: *"the return to skills, for example as measured by the relative wages of college graduate workers to high school graduates, has shown a tendency to increase over multiple decades despite the large secular increase in the relative supply of college educated workers. This suggests that concurrent with the increase in the supply of skills, there has been an increase in the (relative) demand for skills (...) the relative demand for skills is then linked to technology, and in particular to the skill bias of technical change".* [127]

On one hand, the technological advancements of the twentieth century replaced less-skilled workers. On the other hand, it appeared as a complementary activity to high-skilled workers. The latter, through the use of new technologies, were able to increase their productivity. This also led to an increase in wage inequality among workers. The skill-biased technical change, in fact, *"raises the productivity of high skilled workers relative to that of workers with few skills. Gains in relative productivity increase demand for skilled workers' services, enhance their earnings power, and thereby increase earnings inequality".* [128]

For the authors above mentioned, the skill-biased technical change hypothesis is able to explain the mechanism by which high-skill labour demand increased while less-skilled labour demand decreased during the 1970s.

Is therefore important to refer to empirical validation of that theoretical approach at this stage. Several studies have been conducted to verify the validity of this hypothesis and, at the same time, to investigate any other causes of the demand-side shift. An extensive body of research seemed to confirm the role that technological progress played in influencing employment structure. In this connection, some important study on the issue should be mentioned. David Autor, Lawrence Katz and Alan Krueger used the American Current Population Survey (CPS) data to examine if a capital increase is associated with an increase of skilled labour demand and with a decrease of unskilled labour force. The authors first assessed the degree to which computer technologies spread over the period 1984-1993, finding that

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[127] Acemoglu, D. and Autor, D. (2011). *Skill, Tasks, and Technologies: Implications for Employment and Earnings*. In: O. Ashenfelter and D. Card, ed., Handbook of Labor Economics. Elsevier, p. 1044.
[128] Autor, D., Katz, L. and Krueger, A. (1998). *Computing Inequality: Have Computers Changed the Labor Market*?. The Quarterly Journal of Economics, 113(4), p. 1170.

computer usage at work substantially increased in the period under consideration. This led the economists to think that the spread of computers could be one of the possible causes of the high-skilled labour demand increase. They then analysed whether industries that introduced computers into their production processes experienced also an increase in the number of the skilled-workers employed. In industries with high rates of skill-upgrading, increased computer usage was actually found. In conclusion, their analysis showed a positive correlation between the physical capital and skilled workforce: *"industries that experienced the greatest growth in computer use tended to shift their occupational mix towards managers and professionals, and away from administrative support/clerical and service workers. In general, occupations with higher average pay and higher education tended to expand more rapidly in sectors that adopted computer technology at a faster rate".* [129]
Another important study conducted by Krueger in 1993 provided supporting evidence for the skill-bias technical change hypothesis. The author used the Current Population Survey (CPS) data for the period 1894-1989 to test "*whether employees who use computers at work earn more as a result of applying their computer skills*"[130]. Data, which are based on surveys, showed that not only computer usage at work increased by 50% over the period under consideration, but also that highly educated workers were using it most. Then, by cross-referencing data of computer usage against hourly wages, Krueger found that people using computer at work (thus, more skilled) were earning higher wages than those not using it (the salary for computer users was about 10-15% higher). Therefore, according to the author, wage inequality is the result of the skill-bias technical change, and the introduction of computers at work is the prime example of this. A subsequent study conducted by John E. DiNardo in collaboration with Jorn-Steffen Psichke, however, challenged Krueger's conclusion. In the report provocatively entitled "*Have pencils changed the wage structure*

[129] Autor, D., Katz, L. and Krueger, A. (1998). *Computing Inequality: Have Computers Changed the Labor Market*?. The Quarterly Journal of Economics, 113(4), p. 1170.
[130] Krueger, A. (1993). How Computers *Have Changed the Wage Structure: Evidence from Microdata,* 1984-1989. The Quarterly Journal of Economics, 108(1), pp.33-60.

too?"[131] (as opposed to Krueger's "*How computers have changed the wage structure*"[132] report) examined the relationship between hourly wages and the use of calculators, telephones and pens at work, finding a similar effect to that achieved for computer usage (all these commonly-found tools are frequently used in office jobs which are better paid that non-office ones). Therefore, wage inequality appeared not to be related with computer usage. As a consequence of that, there should be other variables that helped to increase wages for more educated workers.

Machin S. and Van Reenen J. examined the relation between skilled workforce and R&D expenditure (the main driver of technological change) for both American and non-American countries (Denmark, France, Germany, Japan, Sweden, UK, and US) by using a regression model. A significant association between the increase in R&D expenditure and the increase in the demand for skilled workforce (which has been measured in terms of skills, wages and employment share in non-production industries) was observed in all the seven countries under consideration, even if to different extents. The outcome of this analysis can be summarized in these few words: "*it is clearly the more R&D-intensive industries that have seen faster increases in nonproduction wage-bill and employment shares and high education shared in the seven countries*"[133]. When R&D expenditure variable is replaced by a variable indicative of computer-usage, the picture does not change. These results provide evidence that the skill-biased technical change has been an international phenomenon whose main effect was to increase demand for skilled workers at the expense of unskilled ones. What the analysis also showed is that, despite the fact that the share of skilled workers on total employment in United Kingdom and in United States of America grew faster than other countries, R&D expenditure, even if sizable, maintained a low rate of growth. Therefore, it appeared that technological change was an important cause of the increase in the demand for skilled employment, but it was not the only one. Other variables surely affected workforce

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131 DiNardo, J. and Pischke, J. (1996). THE RETURNS TO COMPUTER USE REVISITED: HAVE PENCILS CHANGED THE WAGE STRUCTURE TOO?. NBER WORKING PAPER SERIES.
132 Krueger, A. (1993). How Computers *Have Changed the Wage Structure: Evidence from Microdata,* 1984-1989. The Quarterly Journal of Economics, 108(1), pp.33-60.
133 Machin, S. and Van Reenen, J. (1998). *Technology and Changes in Skill Structure: Evidence from Seven OECD Countries*. The Quarterly Journal of Economics, 113(4), p. 1228.

composition. Among these, international trade, the declining role of trade unions and the worsening of the minimum wage should be mentioned. Whereas international trade acts as a demand-side force, institutional factors do not cause a change in employment levels (therefore, they may have affected wage structure but not employment). Berman, Bound and Griliches used the Annual Survey of Manufactures (ASM) and the National Bureau of Economic Research (NBER) data to identify potential causes of the U.S. manufacturing skill-upgrading. Among these, they focused on the effect produced by the international competition, the defence build-up, and the technological progress on workforce composition. The latter was measured by using variables indicative of computer investment and R&D expenditure. We have already seen how technological change, by increasing demand for skilled workers and decreasing that of unskilled ones, is able to determine an upskilling trend pattern. Conversely, the effects produced by international trade on the employment structure, can be explained through the Heckscher-Ohlin theory. According to the model, "*countries tend to export goods that are intensive in the factors with which they are abundantly supplied*"[134]. Therefore, if a country (such as United States) is abundant in skilled labour, it will specialize in the production of skill intensive goods where it has a comparative advantage. Conversely, if a country is abundant in unskilled labour, it will specialize in the production of unskilled intensive goods (this is particularly the case of developing countries). An increase in international trade will led skill-intensive countries to increase their exports and, therefore, the demand for skilled labour. In addition to this, we should consider that companies may outsource production processes in order to exploit the cheap labour force, by concentrating on non-production activities which require the contribution of skilled workers. Therefore, as communication costs decline and trade increases, industries are encouraged to move manufacturing activities abroad. Another possible explanation of the skill-biased shift in the employment structure, could be related to the military build-up: "*defence-related industries tend to employ a disproportionate share of nonproduction workers, particularly with the emphasis put on high tech weapons during the 1980s. Thus, increases in procurements may have shifted manufacturing employment from production to non-*

[134] Krugman, P., Obstfeld, M. and Melitz, M. (2011). *International Economics theory and policy*. 9th ed. Pearson, p. 135.

production workers"[135]. Then, the authors compared the effects that technological innovations, defence build-up and international competition had on the composition of employment, finding that the first one is mainly responsible for the unskilled labour demand drop. Conversely, the effects produced by the other two hypotheses on the relative demand for skills were surprisingly small. The analysis showed that while trade and the defence build-up contributed to a significant but minor part of this change, the skill-biased technological change was the main cause of the skill upgrading. Trade and the defence build-up, in fact, cause a reallocation of the workforce between industries (from those intensive in production workers to those intensive in non-production ones). However, "*less than one-third of the shift of employment from production to nonproduction workers can be accounted for by between-industry shifts; i.e., a reallocation of production away from those manufacturing industries with high shares of production workers in their workforce to those with low shares"*[136]*,* as the two authors claimed. Most of the skill-demand increase occurred within industries and, therefore, it can be attributed to the labour-saving technological change. Only the manufacturing sector is taken into account in their analysis. Therefore, it might seem difficult to draw a general conclusion on the American economy as a whole because of the availability of partial results. However, manufacturing is the sector of the economy that most use trade and outsourcing. *"If trade and foreign outsourcing explain little of the skill upgrading that we observe here, it seems implausible that they can explain much skill upgrading in other branches".*[137] The analysis is based on end-of period data rather than on annual trend. Therefore, by focusing on endpoints information about the overall trend can be missed. This is the kind of criticism that has been made of the study conducted by Berman, Bound and Griliches. However, even if between-industry demand shifts are just one part of the story, it is not possible to deny the role, albeit smaller, that international competition played in influencing employment structure. As Adrian Wood later pointed out, differentiating between intra- and inter-industry effect may be misleading. This is because the outsourcing

[135] Berman, E., Bound, J. and Griliches, Z. (1994). *Changes in the Demand for Skilled Labor within U. S. Manufacturing: Evidence from the Annual Survey of Manufactures*. The Quarterly Journal of Economics, 109(2), p. 376.
[136] Berman, E., Bound, J. and Griliches, Z. (1994). *Changes in the Demand for Skilled Labor within U. S. Manufacturing: Evidence from the Annual Survey of Manufactures*. The Quarterly Journal of Economics, 109(2), p. 368.
[137] Berman, E., Bound, J. and Griliches, Z. (1994). *Changes in the Demand for Skilled Labor within U. S. Manufacturing: Evidence from the Annual Survey of Manufactures*. The Quarterly Journal of Economics, 109(2), p. 392.

phenomenon "*occurs within the traded sector and involves splitting up moderately skill-intensive production activities into their more skill-intensive parts, which remain (and expand) in the North, and their labour-intensive parts, which are moved or subcontracted to the South"*[138]. Therefore, trade could have had a bigger role than that Berman, Bound and Griliches estimated. In other studies, however, the association between trade and demand-side shift is less obvious. For example, a paper by S. Machin and J. Van Reenen, which was produced in conjunction with Thibaut Desjonqueres, showed that both American and non-American manufacturing industries that experienced fastest import growth were not those employing a high-percentage of skilled labour. Furthermore, a significant share of workers with a high level of educational attainment was also found in non-trade sectors, running against the international competition explanation. Could it be that skilled workers, having not found high-paid jobs, have to settle for low-paying and low-skilled jobs? Data would not seem to support this explanation: relative wages (of skilled versus unskilled employees) increased over time. As a result of that, there must be some other reasons for explaining the increase in the skilled employment share and wage in the non-traded sectors: according to the authors, the international trade appeared not to be a valid explanation of the upskilling trend. Therefore, even though many regarded international competition as one of the major causes explaining the observed shifts in wage and employment structure, there is no strong evidence in favour of this line of thought[139]. Other criticism of the trade explanation includes the fact that the volume of trade has been too small to primarily cause the widening of the wage gap. Furthermore, the least developed countries (LDCs) experienced inequality as well, contrary to the provision of international competition explanation[140]. However, trade and technological progress are inextricably linked, and they complement each other to the point that it is difficult to distinguish between the two effects. On one hand, international competition and offshoring are a consequence of the decrease in communication costs which, in turn, were enabled by the development of information and communications technologies

[138] Wood, A. (1998). *Globalisation and the Rise in Labour Market Inequalities*. The Economic Journal, 108(450), pp.1463-1482.
[139] Desjonqueres, T., Machin, S. and Van Reenen, J. (1999). *Another Nail in the Coffin? Or Can the Trade Based Explanation of Changing SkillStructures Be Resurrected?*. The Scandinavian Journal of Economics, 101(4), pp.533-554.
[140] Acemoglu, D. (2003). *Technology and Inequality*. NBER Working Paper.

(ICTs). On the other, companies trading in the global market make an extensive use of digital technologies, determining an increase in the demand for qualified labour. Apart from technological progress and international competition, which act as demand-side forces, institutional factors, other effects may have adversely affected wages of low skilled workers, determining wage inequality. Among these, trade unions and minimum wage, may have played a role in influencing employees' wage structure. Several studies discovered a positive correlation between increasing wage inequality and the decreasing role of trade unions. For example, a study conducted by John DiNardo et al. found that de-unionization "*explains up to twenty-five percent of the change in the standard deviation of men's log wages and up to thirty percent of the change in the standard deviation of women's log wages*"[141] whereas Freeman (1993) recognised a figure of 20% instead of 25%[142]. Others, instead, denied the existence of a positive relationship between the decline of trade unions and wage inequality by pointing out that not only unskilled workers' wages decreased in non-union sectors, but also that pattern occurred even in countries not experiencing significant declines in union representation. Furthermore, the erosion of the real value of the federal minimum wage which occurred during the 1980s may have led to an increase in the wages of workers at the bottom of the skill distribution, rather than in a decrease. Therefore, the key argument against the minimum wage explanation is that there is no time-match. In conclusion, even if wage inequality was mainly driven by an excess of demand for skilled workers in relation to supply, we cannot deny that the changes that have occurred in the labour market supply affected employment and wage structure as well. The large inflow of Asian and Hispanic immigrants which occurred over the period 1973-1990 negatively affected unskilled workers' wages, increasing inequality.

In general, there exist an extensive body of scientific literature examining the effects of technological progress on workforce composition. Most of these studies agree that there is a positive relationship between skilled employment and technology. The latter, is considered to be the main cause of the demand-side shift towards skilled labour. Although the effects

[141] DiNardo, J., Fortin, N. and Lemieux, T. (1995). *Labour Market Institutions and the Distribution of Wages, 1973-1992: a semiparametric approach*. NBER Working Papers.
[142] DiNardo, J., Fortin, N. and Lemieux, T. (1995). *Labour Market Institutions and the Distribution of Wages, 1973-1992: a semiparametric approach*. NBER Working Papers.

produced by other phenomena should not be discarded. In other studies, however, the evidence on the skill biased technical change is less clear. David R. Howell and Edward N. Wolff's analysis should be mentioned in this respect. The authors are of the view that there is no direct relationship between technological capital and high-skilled workforce. According to them, the educational attainment is an imperfect measure of the skill requirements in the workplace. A diversified set of skills, in fact, is required to perform job tasks. Therefore, previous studies that have used years of schooling as a measure of workplace skills delivered incorrect and partial results. To analyse the link between technological change and demand for education they "*developed three alternative industry-level measures of direct skill requirements from the Dictionary of Occupational Titles: cognitive skills, interactive (or 'people') skills, and motor skills*".[143] Cognitive skills are held by professional and technical workers whereas interactive skills are those owned by managers, supervisors and administrators. Motor skills, conversely, are those owned by secretaries, machinist and cashiers and, therefore, they require a lower level of educational compared to the other types of skills. The analysis showed that computer intensity is negatively associated with interactive skills (or supervisory) and positively associated with cognitive (or technical) skills. This does not give, of course, any empirical support for the technology-skill complementarity hypothesis, *"since both types of skill are associated with higher than average educational attainment"* [144]. Several other criticism of the skill-bias technical change hypothesis has been made. In fact, even if several economists agree that the skill-biased technical change (SBTC) has been one of the major causes of the rise in the wage inequality, the hypothesis has been widely criticized. First, because it is not easy to find an appropriate measure of the SBTC to assess its real impact on the wage structure. Research and development expenditure is an imperfect measure of the technological change: in fact, a huge part of R&D does not translate in patentable knowledge and, therefore, in practical applications. Moreover, even computer investment is not an appropriate measure to identify technological progress since it does not take into account the disembodied technical change

[143] Howell, D. and Wolff, E. (1992). *Technical change and the demand for skills by US industries*. Cambridge Journal of Economics, 16(2), p. 144.
[144] Howell, D. and Wolff, E. (1992). *Technical change and the demand for skills by US industries*. Cambridge Journal of Economics, 16(2), pp.127-146.

which, therefore, is not incorporated in any productive factor (it rather refers to a body of knowledge that is applied in production processes). Moreover, some analysts attribute to the technological progress a residual role. This methodology has the fault of attributing to the skill-biased technical change the effects of other variables which are not considered in the empirical study (because they are difficult to measure, or they are not considered at all). Other studies found that wage inequality diminished during the 1990s despite the great technological advances which occurred in the period. During the XX century, in fact, the wage inequality between high-skilled and low-skilled workers became flatter. The skill-biased technical change hypothesis indeed is unable to provide a proper explanation of this phenomenon, as we will see in the next chapter.

2.3.2 Routine-biased technical change

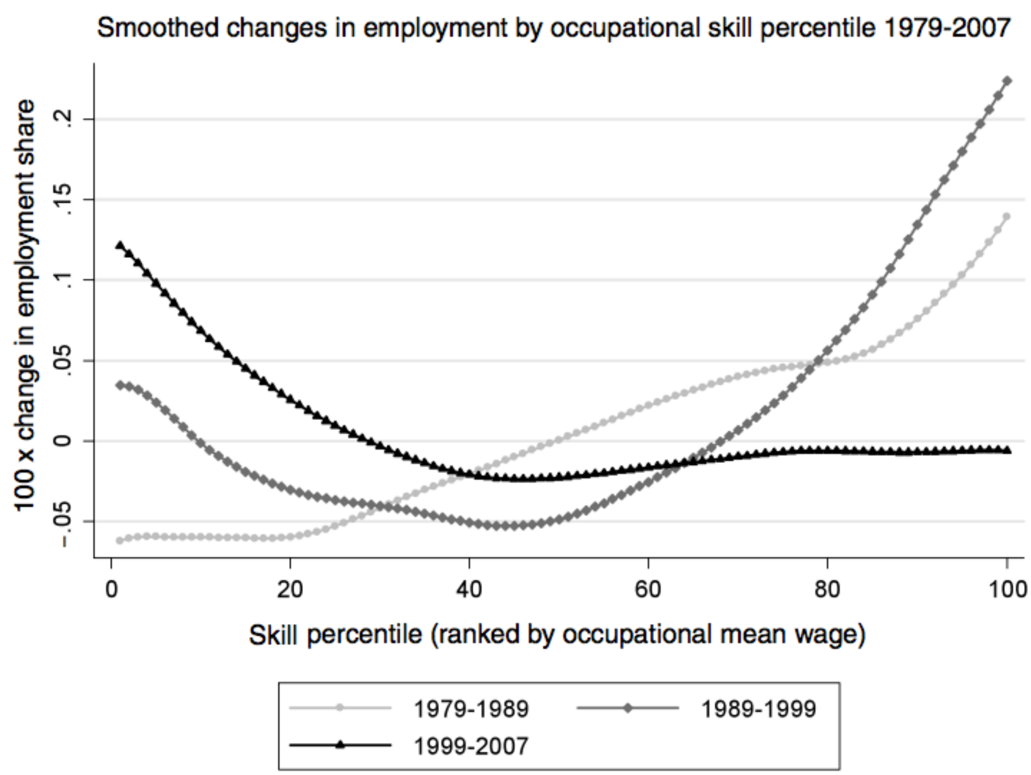
The provision under the previous paragraph, on the skill-model, has proven to be valid for decades. Nowadays, however, the skill-biased technical change hypothesis cannot be used to explain the recent phenomenon of the polarization of the labour market.
In the last few decades, in fact, there has been an increase in labour demand for both low-skilled and high-skilled workers at the expense of the medium-skilled workers, which are easily replaceable by machines.

"*In net, employment changes in the United States during this period were strongly U-shaped in skill level, with relative employment declines in the middle of the distribution and relative gains at the tails*". [145]

Therefore, the impact of technologies on workforce composition can no longer be explained through the use of a model that distinguish between skilled and unskilled workers. New hypotheses have been made to explain the recent phenomenon of the polarization of the labour market. The most important of these decomposes job tasks into two categories: routine

[145] Autor, D. and Dorn, D. (2013). *The Growth of Low-Skill Service Jobs and the Polarization of the US Labor Market*. American Economic Review, 103(5), pp.1555.

and non-routine tasks. Routine operations can be performed by machines while non-routine ones are very complex and, therefore, they are difficult to encode. Compared to the skill-biased technical change hypothesis, this new approach is capable of explaining the employment trend which occurred in the United States and in some European countries during the nineties. In the figure below, "*occupations are ranked on the x-axis by their skill level from lowest to highest, where an occupation's skill rank is approximated by the average wage of workers in the occupation in 1980. The y-axis of the figure corresponds to the change in employment at each occupational percentile as a share of total US employment during the decade*". [146]



Figure[147]

[146] Acemoglu, D. and Autor, D. (2011). *Skill, Tasks, and Technologies: Implications for Employment and Earnings*. In: O. Ashenfelter and D. Card, ed., Handbook of Labor Economics. Elsevier, p. 1070.
[147] Acemoglu, D. and Autor, D. (2011). *Skill, Tasks, and Technologies: Implications for Employment and Earnings*. In: O. Ashenfelter and D. Card, ed., Handbook of Labor Economics. Elsevier, p. 1071.

During the period from 1970 to the end of 1980, highly-skilled employment increased. However, since the nineties, the labour demand for high-skilled workers slowed down. In the meantime, the demand for medium-skilled workers decreased whereas labour demand for low-skilled workers grew, as the graph shows. The phenomenon of labour demand-side shift towards non-routine activities arising from the introduction of technologies into production processes is known as task-biased technical change (TBTC) or routine-biased technical change (RBTC).

Autor et al (2003) first tried to identify a relationship between the use of new technologies and the type of tasks performed by workers. They distinguished between routine and non-routine activities, and between manual and cognitive tasks. The table below summarizes the main findings of their research:

TABLE I

PREDICTIONS OF TASK MODEL FOR THE IMPACT OF COMPUTERIZATION ON FOUR CATEGORIES OF WORKPLACE TASKS

	Routine tasks	Nonroutine tasks
	Analytic and interactive tasks	
Examples	• Record-keeping • Calculation • Repetitive customer service (e.g., bank teller)	• Forming/testing hypotheses • Medical diagnosis • Legal writing • Persuading/selling • Managing others
Computer impact	• Substantial substitution	• Strong complementarities
	Manual tasks	
Examples	• Picking or sorting • Repetitive assembly	• Janitorial services • Truck driving
Computer impact	• Substantial substitution	• Limited opportunities for substitution or complementarity

Figure[148]

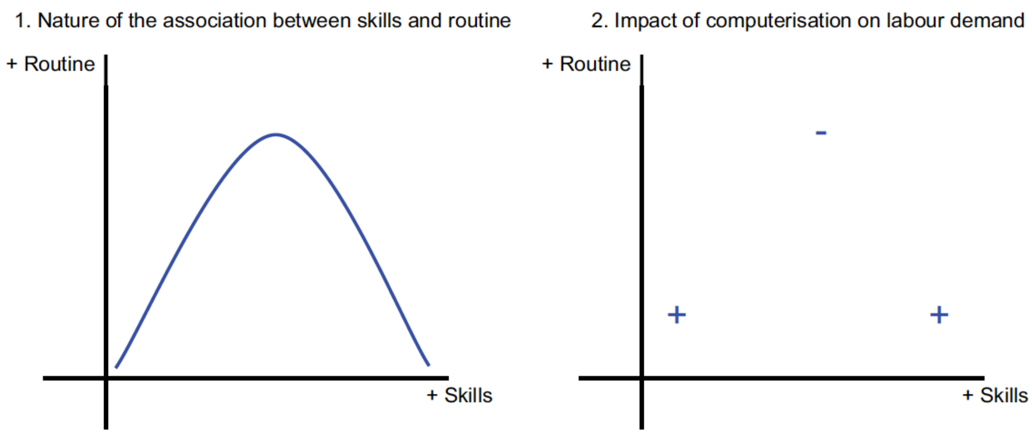
According to the authors, routine tasks *"can be accomplished by machines following explicit programmed rules*"[149], whereas non-routine tasks are those whose *"rules are not sufficiently well understood to be specified in computer code and executed by machines"*[150]. Both these tasks can be manual or cognitive. The first involves physical work while cognitive tasks refer to mental work. As stated by Autor et al (2003), routine tasks can be easily executed by machines which, therefore, replace workers who perform these activities. However, technological progress is complementary to workers who perform non-routine activities given the impossibility to encode these functions. In the past, machines had replaced workers in carrying out manual-repetitive tasks. The advent of the computer and the digital revolution enlarged the range of activities that machines can perform. This has allowed the substitution of human labour also in routine-cognitive tasks. In fact, "*because computers can perform symbolic processing – storing, retrieving and acting upon information – they augment or supplant human cognition in a large set of information-processing tasks that historically were not amenable to mechanization*".[151] As automation costs decrease, employers are encouraged to replace worker with machines in carrying out routine tasks. Labour, in fact, is more expensive than technology. On one hand, this will decrease the demand for workers who perform these tasks. On the other hand, the labour demand for non-routine activities will increase because these functions cannot be codified and, therefore, automated.

Through the digitization of production processes, labour demand for routine-tasks decreases regardless of whether they are conceptual or manual activities. Non-routine tasks, conversely, withstand technological progress.

[148] Autor, D.H., Levy, F. and Murnane, R.J. (2003). *The Skill Content of Recent Technological Change: An Empirical Exploration*. The Quarterly Journal of Economics, 118(4), pp.1283-1286.
[149] Autor, D.H., Levy, F. and Murnane, R.J. (2003). *The Skill Content of Recent Technological Change: An Empirical Exploration*. The Quarterly Journal of Economics, 118(4), p. 1280.
[150] Autor, D.H., Levy, F. and Murnane, R.J. (2003). *The Skill Content of Recent Technological Change: An Empirical Exploration*. The Quarterly Journal of Economics, 118(4), p. 1280.
[151] Autor, D.H., Levy, F. and Murnane, R.J. (2003). *The Skill Content of Recent Technological Change: An Empirical Exploration*. The Quarterly Journal of Economics, 118(4), pp.1284.

Both manual and cognitive routine activities require medium-level skills and, since they follow precise and predefined procedures, they can be easily executed by machines. Non-routine cognitive tasks include all activities that are performed by professionals, managers, engineers, physicians, and, in general, by those with a high level of education. The complexity of these activities demands, in fact, a high level of specific skills. These jobs are difficult to automate because they require creative and problem-solving skills. And similarly, non-routine manual activities, which require low-level skills, are difficult to automate too. Their implementation demands a certain level of adaptability and interaction skills that goes beyond computers abilities. Therefore, the introduction of new technologies favours workers who perform non-routine functions, by increasing their demand, and this leads to the polarization of the labour market.

The figure below illustrates this argument.



Figure[152]

"*The x-axis classifies jobs in a continuum of low to high skills, and the y-axis classifies the same jobs on a continuum of low to high routine content. As shown in the leftmost diagram, jobs in the middle of the skill axis tend to have a higher routine content than jobs in the high or low extremes of this axis. In addition, both are linearly related to labour demand, albeit in opposite directions: higher skill requirements means higher labour demand, while higher*

[152] Eurofound (2014). *Drivers of recent job polarisation and upgrading in Europe*. European Jobs Monitor 2014, p. 46.

routine means lower labour demand. The association between routine and labour demand is stronger, hence the polarisation pattern". [153]

Finally, it is also important to note that no theory explains why routine-tasks are performed by middle-skill workers. Actually, it is more an empirical evidence.

To test the validity of their model, Autor et al (2003) used the U.S. Department of Labour's Dictionary of Occupational Titles (DOT) data. Their analysis showed that industries that introduced computers in their production processes reduced indeed the labour demand for workers employed in manual and cognitive routine tasks during the period 1970-1998. At the same time, they increased the demand for workers employed in non-routine jobs.

The routine-biased technical change hypothesis which states that the introduction of technologies into production processes would have reduced the demand for routine work and would have significantly increase non-routine labour demand, has been demonstrated by several studies. A work stream compares the effects that technological innovations and international competition had on employment levels for the purpose of identifying the source of the routine demand-side shift. These are viewed as the two main economic forces behind job polarization. Autor et al (2013), to name a few, drew attention to the differing effects of technological innovations and of international competition (in particular, the Chinese import competition) on U.S. employment levels. While imports have a negative effect on employment levels, irrespective of the skill category (even if middle-skill employment declines are more substantive), technological developments do not substantially affect the number of people employed but, instead, they cause a change in the workforce composition. The introduction of technologies into production processes, in fact, reduces the demand for routine jobs. However, "*these declines in routine employment are largely offset by increasing employment abstract or manual task-intensive occupations which tends to comprise the highest and lowest paid jobs in the economy*". [154] Therefore, according to Autor, Dorn and Hanson's analysis, technology changes employment composition, in that it favours only certain categories of workers, without altering employment levels.

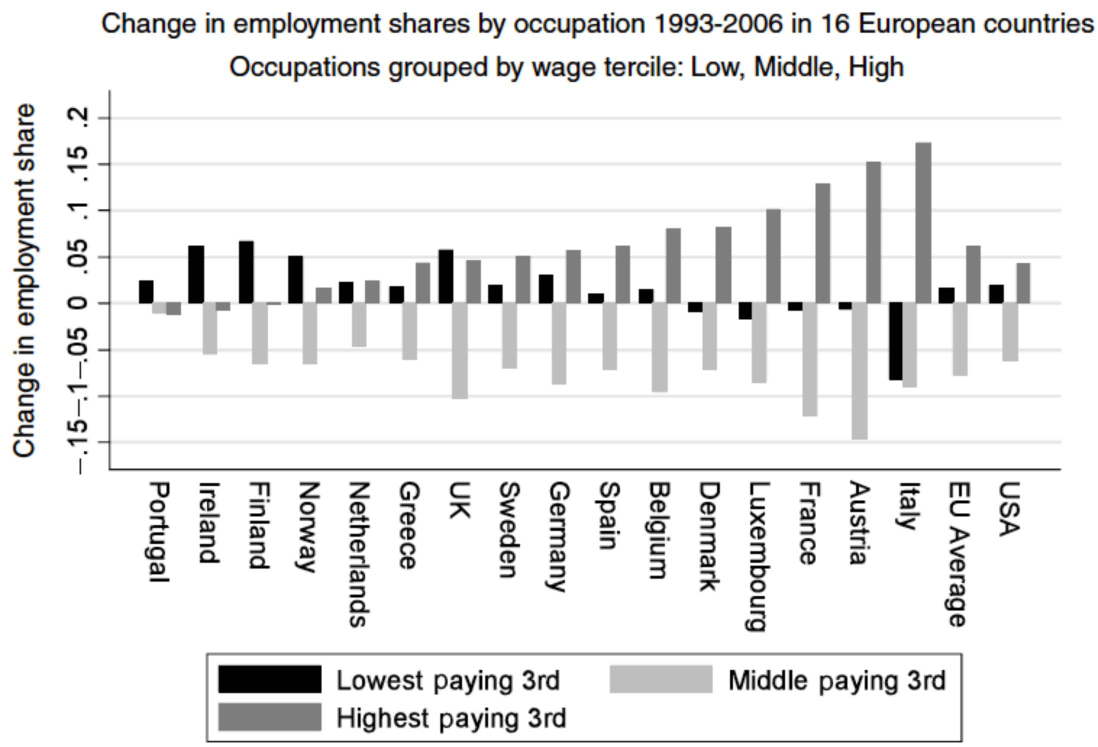
[153] Eurofound (2014). *Drivers of recent job polarisation and upgrading in Europe*. European Jobs Monitor 2014, p. 46.

[154] Autor, D., Dorn, D. and Hanson, G. (2015). *Untangling Trade and Technology: Evidence from Local Labour Markets*. The Economic Journal, 125(584), p. 644.

According to Jaewon Jung and Jean Mercenier, possible explanations of the labour market polarization include the routine-biased technical change which substitutes workers in carrying out routine tasks, and globalization (in particular, offshoring and outsourcing) which substitutes local with foreign labour in the most tradeable jobs. The authors used a general equilibrium model to compare the effects that offshoring and technical change have on the employment structure. Their analysis showed that routine-biased technical change (RBTC) and globalization have similar effects on workforce composition. However, there are qualitative differences between the two phenomena. By outsourcing the production of some tasks local labour demand for routine workers decreases whereas foreign labour demand for routine workers increases. Only multinationals firms are able to outsource their production processes and take advantage of the cheap foreign labour costs, because of the high-fixed costs involved. Therefore, these companies will be affected by a decrease in the routine labour demand. Non-multinational firms will, conversely, produce everything in house and they will not be subject to the routine demand drop. Therefore, globalization is not capable of explaining why routine labour demand decreases within the same industry. The routine-biased technical change (RBTC), conversely, affects the way routine activities are carried out within each industry and, therefore, it is mainly responsible for the polarization of labour market[155].

The phenomenon of the polarization of employment did not occur exclusively in the United States. As can be seen in the figure below, even European countries have been affected.

[155] Jung, J. and Mercenier, J. (2014). *Routinization-biased technical change and globalization: understanding labor market polarization*. Economic Inquiry, 52(4), pp.1446-1465



Figure[156]

Goos et al (2009) data have been used in drawing up the figure which appears above. On the y-axis is the change in employment share, on the x-axis is the countries. Goos, Manning, and Salomons used "*the harmonized European Union Labour Force Survey (ELFS) data (...) to map occupational employment changes in 16 European countries over the period 1993-2006*".[157] The authors grouped professions according to the wage level: low, medium and high. For each of these categories, they analysed the relative change in the employment share. In several European countries the phenomenon of the polarization of labour market occurred in the late 1990s. Almost all the sixteen countries considered, in fact,

[156] Acemoglu, D. and Autor, D. (2011). *Skill, Tasks, and Technologies: Implications for Employment and Earnings*. In: O. Ashenfelter and D. Card, ed., Handbook of Labor Economics. Elsevier, p. 1073.
[157] Goos, M., Manning, A. and Salomons, A. (2009). *Job Polarization in Europe*. American Economic Review, 99(2), p.58.

experience a decrease in the employment share for medium-skill jobs. At the same time, the employment share for high and low-skill jobs increased.

"*On average, the low- and high-paying occupations increase their employment shares by 6 and 2 percentage points (or 9 and 22 percent), respectively, whereas the middling occupations decrease their employment share by 8 percentage points (or 17 percent)".*[158]

The phenomenon of polarization of labour market is more pronounced in Austria, France, United Kingdom and Belgium. It is less pronounced in other countries, such as Portugal, where medium-wage occupations had a smaller drop.

There could be any number of reasons why labour market became polarized. The authors tested different hypotheses to identify the source of the polarization, such as the routinization hypothesis, the offshoring, and the role of institutions. Their analysis showed that *"pervasive job polarization is in line with the evidence that in advanced countries, technologies are becoming more intense in the use of non-routine tasks concentrated in high-paid and low-paid service jobs, at the expense of routine tasks concentrated in manufacturing and clerical work. The evidence for alternative explanations – offshoring and inequality – is much weaker".* [159]According to the authors, technological change is the most important factor behind the observed changes in the employment structure that has characterized European countries during the period 1993-2006.

A further important analysis on the changes that have occurred in the European job structure is offered by the European Foundation for the Improvement of Living and Working Conditions (Eurofound). The report drawn up by the Agency in 2014 showed that 5 million jobs were lost in Europe over the period 2008-2011. Moreover, employment levels declined by 1.3 million during the period 2011-2013. Medium-skilled workers were the most affected by the employment reduction. Throughout both study periods, in fact, the medium-skilled employment substantially declined. At the same time, employment grew for both high-skilled and low-skilled workers. "*Overall, the pattern can be described as one of polarisation, meaning that relative employment growth is greatest at either end of the wage distribution*

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[158] Goos, M., Manning, A. and Salomons, A. (2009). *Job Polarization in Europe*. American Economic Review, 99(2), p. 60.

[159] Goos, M., Manning, A. and Salomons, A. (2009). *Job Polarization in Europe*. American Economic Review, 99(2), p. 62.

and weakest in the middle".[160] A number of factors might have affected and, therefore, changed the occupational structure. Eurofound considers four hypotheses: the skill-biased technical change (SBTC), the routine-biased technical change (RBTC), globalization, and the institutional change. We have already seen how technological progress increases the demand for high-skill workers whose competences cannot be encoded and, therefore, automated. Consequently, the skill-biased technical change hypothesis can provide a justification for the upskilling trend of the recent decades. However, it is not able to explain why low-skill labour demand increased over the same period. The routine-biased technical change hypothesis (RBTC) is an updated version of the skill-biased technical change one (SBTC). According to it, technological progress, by substituting workers in carrying out routine tasks, reduces the demand for middle-skilled labour leading, consequently, to the polarization of employment. "*The impact of trade on the jobs structure is biased in a way that is similar to that proposed for technology: because some types of economic activity (or tasks or jobs) are more tradable than others, increasing levels of trade have an uneven effect on the demand for different types of labour*".[161] Since the most tradeable jobs are those requiring a middle-level of education, the globalization hypothesis is capable of explaining the polarization trend. Similarly, market institutions such as minimum wages and trade unions, by protecting low-skilled workers, are able to explain why labour demand has scarcely decreased for this category of workers compared to what occurred to medium-skilled workers. The impact of each of these hypotheses on the employment structure was analysed using regression models. The predicted shifts of employment were confronted with the real shifts that occurred in the twenty-three European countries over the period 1995-2007. The analysis concluded that only the cognitive index (which has been used to test the effectiveness of the skill-biased technical change hypothesis) was able to predict the real trend of employment, whereas all the other indices, including the routinization index, delivered partial results. Therefore, technological progress appeared to be the cause of the increase in the high-skilled labour demand, whereas it seemed to be unrelated with the decrease in the routine or middle-skill labour demand. Furthermore, what emerges from the

[160] Eurofound (2014). *Drivers of recent job polarisation and upgrading in Europe*. European Jobs Monitor 2014.
[161] Eurofound (2014). *Drivers of recent job polarisation and upgrading in Europe*. European Jobs Monitor 2014, p. 49.

analysis carried out by Eurofound is that skills cannot be represented through the employees' average-wage because European wage structure is influenced by several institutional, cultural, and social factor which are different from one country to another one. In conclusion, Eurofound analysis did not provide any evidence in support of the routine-biased technical change hypothesis as the routinization index showed to have a small impact on the employment structure compared to the cognitive one:

"*The RBTC argument does not fit well with the observed patterns for Europe in the period studied here. Of the two key variables for the task model, the cognitive task content seems more closely associated with the observed patterns of structural change in European labour markets. However, this association goes generally in the direction of upgrading rather than polarization, with only a small non-linear effect in a couple of cases. This fits the traditional argument of the skills-biased technical change (SBTC) much better, which would have predicted a more or less linear association between skills and labour demand as a result of computerisation*".[162]

In spite of the criticism voiced, the routine-biased technical change hypothesis has been regarded by many economists as the major explanation of the polarization of labour market. However, nowadays, the importance of the routine-biased technical change hypothesis is waning. This is because the introduction of the technologies of Industry 4.0 into production processes led to a blurring of boundaries between routine and non-routine task. Many of the activities classified as "non-routine" can in practice be automated and executed by machines and robots. For example, until very recently, it seemed impossible to automate the ability to drive a vehicle. Nowadays, Google's driverless cars are used on the road. But, this is just one of the many examples that could be made on existing technologies' ability to perform non-routine tasks. Autor et al (2003) model, therefore, is no longer valid and it cannot be used to forecast the impact that the next-generation technologies will have on workforce composition. Considering the recent technological developments, the two Oxford researchers Frey and Osborne modified the task model for modern times. While the task model states that computer can only perform routine work, Frey and Osborne's model provides that the

[162] Eurofound (2014). *Drivers of recent job polarisation and upgrading in Europe*. European Jobs Monitor 2014.

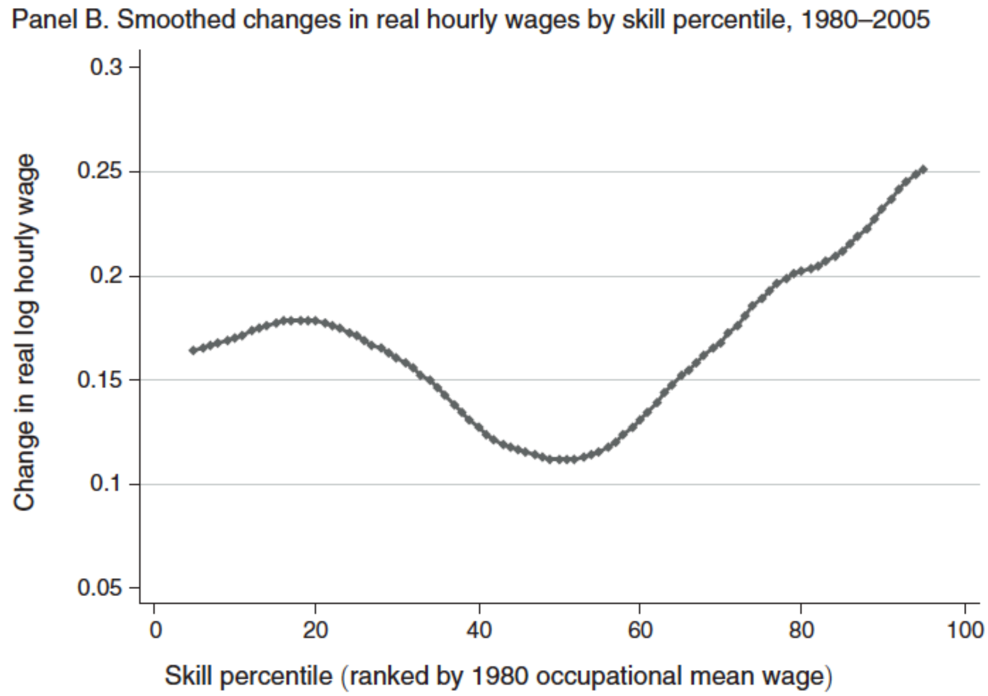
human/machines substitution also applies to non-routine activities, to the exclusion of those that have engineering problems to computerisation. The "*extent of job computerisation will thus be determined by technological advances that allow engineering problems to be sufficiently specified, which sets the boundaries for the scope of computerisation*"[163].

For a more detailed discussion of the impact of the new 4.0 technologies on labour market dynamics, please refer to the next chapter.

2.4 The impact of technological progress on earnings inequality

After reviewing all the possible consequences deriving from the use of new technologies on employment levels and on the workforce composition, the relationship between technological progress and wage levels will be analysed in this paragraph. According to the skill-biased technical change hypothesis, technological progress increases the demand for high-skilled labour while, at the same time, it decreases the demand for unskilled labour, whose wages will fall accordingly. This rises wage inequality among workers. Several studies provided empirical evidence to confirm this hypothesis by showing a growing wage inequality between American skilled and unskilled workers during the 1970s. Starting from the 1990s, however, the U.S. economy experienced a growing polarization in wages: the wages of high and low-skilled workers increased whereas those of middle-skill workers decreased.

[163] Frey, C. and Osborne, M. (2013). The future of employment: How susceptible are jobs to computerisation?. Technological Forecasting and Social Change, 114, p. 14.



Figure[164]

The figure above shows the trend followed by the American real hour wage ranked by the skill level over the period 1980-2005. On the y-axis is the change in real hourly wage, on the x-axis is the skill percentile. It is evident from the graph that "*wage growth is strikingly U-shaped in skill percentile, with the greatest gains in the upper tail, modest gains in the lower tail, and substantially smaller gains toward the median".*[165] Wages of skilled workers increased at a rate of 37% between 1980 and 2010 and those of low-skilled ones at a smaller rate of 7%. The growth rate of medium-skilled workers' salary stayed flat[166]. To explain this phenomenon, a new hypothesis emerged. This is known as the task-biased technical change (TBTC) or routine-biased technical change (RBTC). According to it, technologies replace

[164] Autor, D. and Dorn, D. (2013). *The Growth of Low-Skill Service Jobs and the Polarization of the US Labor Market*. American Economic Review, 103(5), p.1554.
[165] Autor, D. and Dorn, D. (2013). *The Growth of Low-Skill Service Jobs and the Polarization of the US Labor Market*. American Economic Review, 103(5), pp.1556.
[166] Autor, D. and Dorn, D. (2013). *The Growth of Low-Skill Service Jobs and the Polarization of the US Labor Market*. American Economic Review, 103(5), pp.1556.

workers in carrying out routine tasks and complement workers who perform non-repetitive tasks.

As technology costs decrease, employers are encouraged to replace the expensive labour with machines in carrying out repetitive jobs. If the demand for medium-skill workers decreases, their wages will fall accordingly. Nevertheless, non-routine activities, either manual or cognitive, will be favoured by technological progress which will increase labour demand for this category of workers. In particular, if demand for high-skilled cognitive workers increases, wages will increase too.

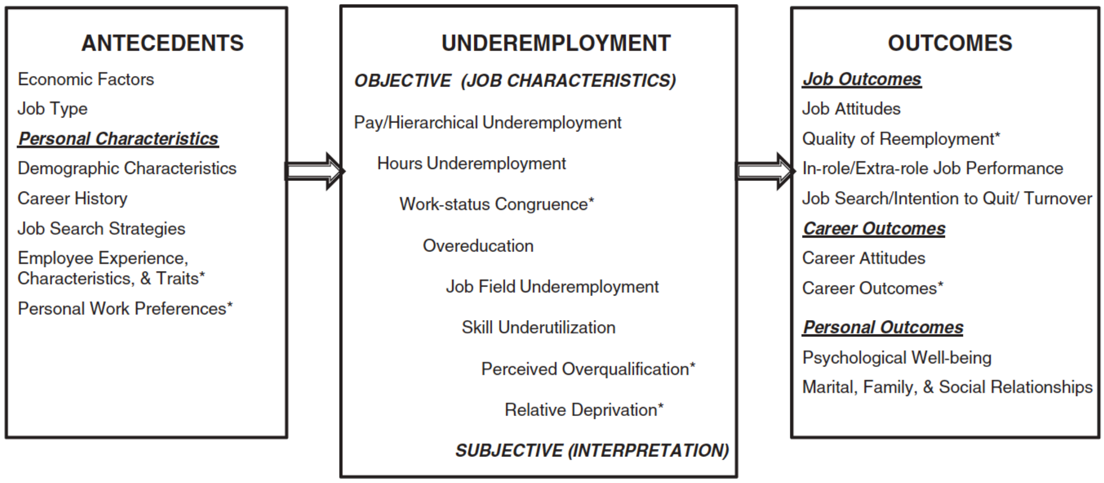
However, the impact of technological progress on non-routine manual workers' wages is ambiguous, because of two quite different phenomena.

The first effect is related to the fact that technological progress increases the workers' productivity and, therefore, their labour demand. The second effect is the result of the increase in the available workforce. In fact, routine workers replaced by machines will move towards non-routine manual works. Consequently, non-routine manual workers' supply will increase. Carry out non-routine manual works requires a lower level of educational attainment compared to routine works. As a result of that, routine workers will be over-skilled and over-qualified in relation to the educational level required for the performance of non-routine manual jobs. This phenomenon is known as underemployment and it *"occurs when a worker is employed in a job that is inferior by some standard"*.[167] Underemployment can be measured through objective or subjective dimensions. An example of the former is when workers earn lower wages than those they earned before, or they fulfil a role which is inferior to the position they previously carried out. A subjective dimension, conversely, may concern the worker's belief of deserving a better job or a better pay. According to Frances M. McKee-Ryan and Jaron Harvey there can be a number of antecedents of underemployment. Among these, several studies have shown evidence of a correlation between job positions and underemployment. The underemployment phenomenon, in fact, appeared to be more prevalent among middle-managers: the latter were the ones most severely affected by downsizing and layoffs. This would provide support to the routine-biased technical change

[167] McKee-Ryan, F. and Harvey, J. (2011). "*I Have a Job, But . . .": A Review of Underemployment*. Journal of Management, 37(4), p. 962.

hypothesis that has driven many middle-skilled workers to move to lower-skilled and lower-paid jobs, as they have been replaced by machines in performing routine works. Other studies, however, showed that "*highly educated workers are more likely to experience higher levels of underemployment because these workers are apt to be employed in jobs that are not commensurate with their education*"[168]. This may disprove, however, the routine-biased hypothesis owing to the fact that, although it is true that middle-skilled workers had to settle for low-level positions, high-skilled workers were able to find a job without struggle because of the increasing demand for skilled workforce. In general, various studies have found that underemployment tend to be more frequent during economic downturns and for those industries facing a period of crisis, while it appeared to be unrelated to gender, race, or age. What the report also shows is that underemployment is negatively linked to job satisfaction and job involvement and positively related to work alienation. Workers will not commit themselves to performing their jobs to full capacity if they perceive to be overqualified for the position they do. All this could also lead to the employees' withdrawal. Underemployment can hurt not only workers' performance level, but it can also damage workers' psychological health and create feelings of frustration, anxiety, and insecurity. Firms have to understand that over-skilled employees are a valuable resource and they must exploit their full potential through an appropriate incentive scheme. In fact, "*an overqualified employee is capable of high levels of job performance when the organization provides opportunity for challenge and advancement, fulfils the employee's psychological contract, and empowers the employee to do his or her best work*".[169] McKee-Ryan and Harvey's main research findings are represented in the table below which summarizes underemployment's antecedents, dimensions, and outcomes:

[168] McKee-Ryan, F. and Harvey, J. (2011). "*I Have a Job, But . . .": A Review of Underemployment*. Journal of Management, 37(4), p. 976.
[169] McKee-Ryan, F. and Harvey, J. (2011). "*I Have a Job, But . . .": A Review of Underemployment*. Journal of Management, 37(4), p. 982.

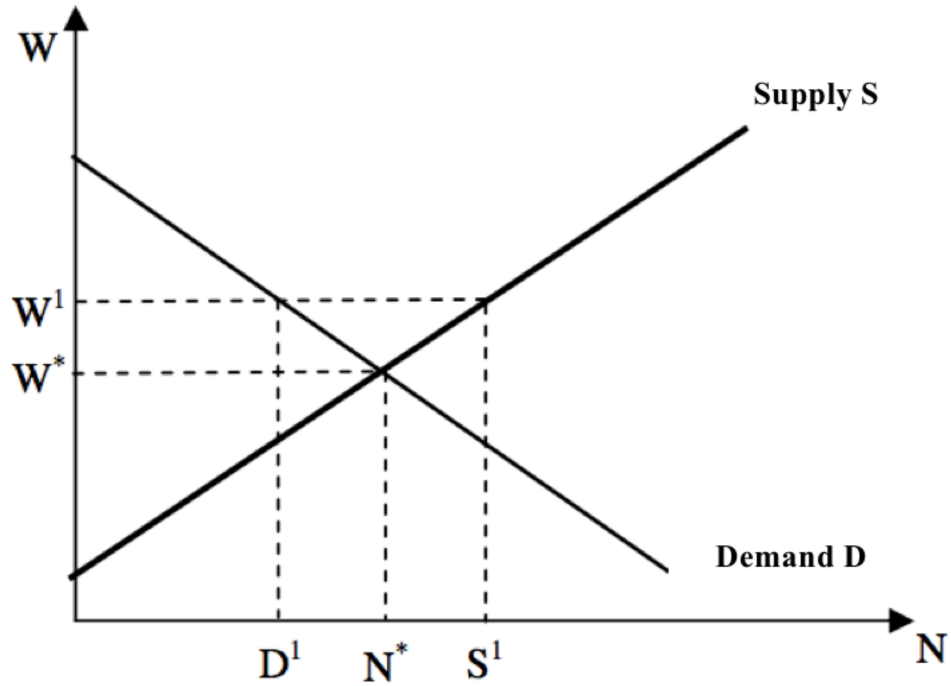


Figure[170]

After analysing underemployment's causes and consequences, we should get back to the main topic of the paragraph: how technological progress determines earnings inequality. As stated above, on one hand, technological progress increases the demand for non-routine manual workers, on the other, the process of routine labour reallocation increases workers' supply. In this connection, it should be noted that another cause which contributed greatly to increasing the available workforce was the flow of immigration. This phenomenon, in fact, has increased significantly in America and in other advanced nations (in particular in Italy) during the 1990s, expanding low-skilled workers' supply even more.

If workers' supply increases more than the demand, wages will fall accordingly. If not, wages will increase. In the latter case, the polarization of wages will occur. Wages, in fact, are determined by the intersection between labour demand and supply, as it is shown in the graph below.

[170] McKee-Ryan, F. and Harvey, J. (2011). "*I Have a Job, But . . .": A Review of Underemployment*. Journal of Management, 37(4), p. 971.



Figure[171]

On the y-axis is the wages (W), on the x-axis is the number of people employed (N).
If labour supply is greater than labour demand, workers will have less bargaining power and they will be forced to accept lower wages.
"*During the 1980s, the supply effect prevailed, with a consequent reduction in the less-skilled manual workers' wages. This has led to a skill-biased trend and, therefore, to a monotone skill-wage growth. During the 1990, conversely, the productivity effect due to an increase in the demand for routine tasks prevailed, with a consequent increase in the non-routine manual workers' wages*".[172]
The analysis that we applied to assessing technological impact on social inequality points out that not everyone benefits from technological progress but, on the contrary, it creates winners and losers. Technological progress shift production frontier upward, increasing overall

[171] Blanchard, O., Amighini, A. and Giavazzi, F. (2011). *Macroeconomia: una prospettiva europea*. Bologna: Il mulino.
[172] Magazzino, C. and Romagnoli, G.C. (2014). *Legge di stabilità e finanza pubblica in Italia*. FrancoAngeli.

wealth. However, there is no guarantee that wealth is distributed fairly. In general, there are three ways for technological change to affect income distribution: first, through effects on employees, secondly, through the rewards earned by capital owners and, finally, through the rewards earned by "superstars".

As seen from the above, technological progress increases the labour demand for non-routine workers while, at the same time, it decreased the labour demand for routine workers. As a result of that, those who have developed non-routine skills will see their wages to increase and, therefore, they will benefit from technological progress. Conversely, if machines directly replace routine workers, the latter will see their wages to drop accordingly. Therefore, they are traditionally counted among those who are suffering from technological change. Whereas the polarization of employment took place both in United Stated and in Europe, the polarization of wages is just an American phenomenon. For the United States, several studies showed that the so-called "polarization of wages" process occurred. In Europe, this evidence is less clear. Goos et al. examined the relationship between technological progress, employment and wages in 16 European countries for the period 1993-2006. What the report showed is that technological progress is the main cause of the polarization of employment whereas it appeared to be unrelated with the wage structure which has not become polarized: "*data suggests that relative occupational wage movements in Europe are not strongly correlated with (...) technology and offshoring variables. This result differs from evidence for the US but it is not necessarily inconsistent with it since many European countries have institutions (e.g. minimum wages and collective bargaining) that mute or stop a wage response, especially across middling and lower-paying occupations*"[173].

Similar results were found by Ragusa, Naticchioni and Massari. The authors examined whether 12 European countries (Austria, Belgium, Denmark, Finland, France, Germany, Ireland, Italy, Spain, Sweden, Netherlands and United Kingdom) have been subject to the trend of the polarization of wages. By using both an industry- and individual- level analysis, they found that "*technological progress, as measured by the ICT intensity in capital compensation, has had an impact on job polarization through hours worked. However, (...)*

[173] Goos, M., Manning, A. and Salomons, A. (2011). Explaining Job Polarization: The Roles of Technology, Offshoring and Institutions. SSRN Electronic Journal, p. 15.

[they] do not find evidence that wages have significantly responded in the same way to technology". This is caused by institutional factors, which differ between America and Europe.[174]

"Capital versus labour" is the second set of winners and losers created by technological progress. "*Most types of production require both machinery and human labour (...) If the technology decreases the relative importance of human labour in a particular production process, the owners of capital equipment will be able to capture a bigger share of income from the goods and services produced*"[175]. Therefore, capital owners will become richer whereas workers, whose wages will fall, will become poorer. This helps to increase earning inequality among employer and employees. Empirical data showed that capital share used in production process increased over time compared with that of labour. As a result of that, capital owners' compensations increased while labour's compensations decreased. "*According to the recently updated data from the U.S. Commerce Department, recent corporate profits accounted for 23.8% of total domestic corporate income, a record high share that is more than 1 full percentage point above the previous record. Similarly, corporate profits as a share of GDP are at 50-yeat highs. Meanwhile, compensation to labour in all forms, including wages and benefits, is at a 50-year low. Capital is getting a bigger share of the pie, relative to labour*"[176].

For completeness, another set of winners and losers of digital economy should be mentioned in this respect: it concerns the "superstar versus everyone-else" group. "*Many industries are winner-take-all or winner-take-most competitions, in which a few individuals get the lion's share of the reward*"[177]. The best performer (also known as superstar), in fact, is capable of obtaining the highest compensations and increasing its market

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[174] Naticchioni, P., Ragusa, G. and Massari, R. (2014). Unconditional and Conditional Wage Polarization in Europe. Forschungsinstitut zur Zukunft der Arbeit Institute for the Study of Labor.

[175] Brynjolfsson, E. and McAfee, A. (2011). Race against the machine: how the digital revolution is accelerating innovation, driving productivity, and irreversibly transforming employment and the economy. Lexington, Massachusetts: Digital Frontier Press, p. 30.

[176] Brynjolfsson, E. and McAfee, A. (2011). Race against the machine: how the digital revolution is accelerating innovation, driving productivity, and irreversibly transforming employment and the economy. Lexington, Massachusetts: Digital Frontier Press, p. 31.

[177]Brynjolfsson, E. and McAfee, A. (2011). Race against the machine: how the digital revolution is accelerating innovation, driving productivity, and irreversibly transforming employment and the economy. Lexington, Massachusetts: Digital Frontier Press, p. 29.

share at the expense of competitors, who, conversely, will hold a marginal share of the market. Let's think, for example, at the European football players Cristiano Ronaldo or Lionel Messi whose wages are the highest in the football sector. While a "serie D" player earns 20.000 euros per year, the average wage for a "serie A" football player is about half a million of euros per year. Furthermore, within the "serie A" category, some are able to earn even 10 million of euros per year. Even if the majority of the aspiring football players don't get paid to play soccer, the most talented of them are able to gain success and obtain higher salaries. The same could be said for some actors and actress with extraordinary talents are able to rule the market and earn high wages compared to the sector average. This is known as "*the phenomenon of superstars, wherein relatively small number of people earn enormous amounts of money and dominate the activities in which they engage*"[178]. The explanation of why few people earn higher wages compared to other performing the same job is that workers are not perfect substitutes: individuals have different skills and they are compensated based upon their value. Since technology allows companies to improve goods' performance and quality as well as to create new ones, those who seize the occasion offered by digital technologies will be able to obtain a big share of the market. This results in income disparities between superstars and everyone else. An example of a winner-take-all company is Facebook. The social network was founded by Mark Zuckerberg in 2004. The nineteen-years-old student was able to identify an unmet need before anyone else and use digital tools to create something new, by making full use of his capacities. The social network benefited from the network effect which *"occurs when the value of a product or service goes up with the number of people using it*"[179]. Therefore, as the number of users grew, Facebook's value increased accordingly. This led the social network to almost monopolise the market. Any new company seeking to join the business will not get any market share since nobody would leave an established network for a new one.

[178] Rosen, S. (1981). The Economics of Superstars. The American Economic Review, 71(5), pp.845-858.
[179] Malik, O. (2015*). In Silicon Valley Now, It's Almost Always Winner Takes All.* The Newyorker. [online] Available at: https://www.newyorker.com/tech/elements/in-silicon-valley-now-its-almost-always-winner-takes-all [Accessed 19 May 2018].

Chapter 3: The employment scenario with the advent of Industry 4.0

3.1 Industry 4.0

The history of mankind has been affected by millennia of technological progress: starting with the advent of the steam engine and the electric motor, up to the most recent diffusion of personal computers (PCs) and the digitization. Nowadays, we are standing at the dawn of a fourth industrial revolution that it is going to have a massive impact on productive sectors and on the economy as a whole.

The aim of this last chapter is to describe the phenomenon of the fourth industrial revolution, also known as Industry 4.0, and how it is being implemented across different countries. In order to do so, we will first assess whether there is a new and distinct industrial revolution, then a comparative overview of the national implementation plans will be made. It is also important to investigate what the effects of Industry 4.0 will be on labour market dynamics. Consequently, the second part of the chapter is dedicated to analysing the impact of the next-generation technologies on employment levels. Then we will finish the discussion by describing Frey and Osborne's task model that may be used to assess what the high-risk and low-risk occupations are and, therefore, to estimate how technological progress will impact on workforce composition. In particular, we will question the routine-biased technical change hypothesis, claiming that it cannot be considered as valid since 4.0 technologies are apparently able to perform non-routine activities as well.

"*The first five years of the twenty-first century saw a renewed wave of innovations and investments, this time less focused on computer hardware and more focused on a diversified set of applications and process innovations*".[180] Contrary to earlier industrial revolutions, the fourth industrial revolution will not simply rely on an individual enabling technology but rather on a set of interconnected technological infrastructures. Big data, artificial intelligence,

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[180] Brynjolfsson, E. and McAfee, A. (2014). *The second machine age*. 1st ed. New York: W. W. Norton & Company, p. 60.

augmented reality (AI), robotics, Internet of Things (IoT), and the additive manufacturing are just some of the numerous innovations characterising our age. Let’s take a quick look at them:

- Big Data: the term is used to indicate a set of technologies used to collect and process data and information on the Internet. For example, they allow for analyzing data concerning market trends, consumers preferences and demand for goods and services.
- Additive manufacturing: refers to the industrial use of the 3D printing technology. It has several advantages: it let companies to customize products, to reduce material wastes and to overcome the limits of traditional technologies[181].
- Internet of Things (IOT): relates to the possibility of “*embedding sensors and actuators in machines and other physical objects to bring them into the connected world*”[182].
- Digital manufacturing: employs a wide range of technologies (such as IOT, big data, 3D printing) to simulate production cycle before its real implementation. This allows for seeing room for improvements, detecting defects and improving efficiency[183].

Only a small number of technologies have been described above; however, there list goes on. For example, in 2016, the McKinsey Global Institute issued a report detailing twelve new technologies that will have soon a significant impact on our society. These technologies are described in the figure below.

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[181] Magone, A. and Mazali, T. (2016). *Industria 4.0: Uomini e macchine nella fabbrica digitale*. Milano: Guerini, pp. 70-76.
[182] Manyika, J., Chui, M., Bughin, J., Dobbs, R., Bisson, P. and Marrs, A. (2013). *Disruptive technologies: Advances that will transform life, business, and the global economy*. McKinsey Global Institute Report, p. 18.
[183] Magone, A. and Mazali, T. (2016). *Industria 4.0: Uomini e macchine nella fabbrica digitale*. Milano: Guerini, pp. 70-76.

Twelve potentially economically disruptive technologies

Mobile Internet	Increasingly inexpensive and capable mobile computing devices and Internet connectivity
Automation of knowledge work	Intelligent software systems that can perform knowledge work tasks involving unstructured commands and subtle judgments
The Internet of Things	Networks of low-cost sensors and actuators for data collection, monitoring, decision making, and process optimization
Cloud technology	Use of computer hardware and software resources delivered over a network or the Internet, often as a service
Advanced robotics	Increasingly capable robots with enhanced senses, dexterity, and intelligence used to automate tasks or augment humans
Autonomous and near-autonomous vehicles	Vehicles that can navigate and operate with reduced or no human intervention
Next-generation genomics	Fast, low-cost gene sequencing, advanced big data analytics, and synthetic biology ("writing" DNA)
Energy storage	Devices or systems that store energy for later use, including batteries
3D printing	Additive manufacturing techniques to create objects by printing layers of material based on digital models
Advanced materials	Materials designed to have superior characteristics (e.g., strength, weight, conductivity) or functionality
Advanced oil and gas exploration and recovery	Exploration and recovery techniques that make extraction of unconventional oil and gas economical
Renewable energy	Generation of electricity from renewable sources with reduced harmful climate impact

Figure[184]

[184] Manyika, J., Chui, M., Bughin, J., Dobbs, R., Bisson, P. and Marrs, A. (2013). *Disruptive technologies: Advances that will transform life, business, and the global economy*. McKinsey Global Institute Report, p. 4.

The large-scale introduction of the twenty-first century technologies into production processes is tacking on the characteristics of a new and real revolution. Of course, not all economists agree that the fourth industrial revolution is underway. Among these, Jeremy Rifkin believes that the third industrial revolution has just bore its fruits. According to the author, "*the great economic revolutions in history occur when new communication technologies converge with new energy systems*".[185] For example, the author believes that the factors that contributed to the development of the first industrial revolution were precisely the invention of the press and the discovery of the coal-based energy. Similarly, the convergence between the electronic communications (telegraph, telephone, radio, and television) and the oil-based energy led to the development of the second industrial revolution[186].

"*Today, Internet technology and renewable energies are beginning to merge to create a new infrastructure for a Third Industrial Revolution (TIR) that will change the way power is distributed in the 21st century. In the coming era, hundreds of millions of people will produce their own renewable energy in their homes, offices, and factories and share green electricity with each other in an "Energy Internet" just like we now generate and share information online*".[187]

The report clearly shows that the co-existence of five different factor is needed to ensure the development of a third industrial revolution. These are: the shifting to a renewable energy, the microgeneration of sites to collect energy, the development of the hydrogen technologies needed to store energy, the development of an "*Energy Internet Grid*" accessible to everyone that would allow users to produce and distribute electricity from their home as easily as information is shared online, and the shifting to electric vehicles. Consequently, renewable energies, the interconnected electric systems, cloud technology are all key components of the Third Industrial Revolution which is, therefore, at an early stage in its development, as claimed by Rifkin.

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[185] Rifkin, J. (2012*). The Third Industrial Revolution: How the Internet, Green Electricity, and 3-D Printing are Ushering in a Sustainable Era of Distributed Capitalism.* The World Financial Review, p. 8.

[186] Rifkin, J. (2012*). The Third Industrial Revolution: How the Internet, Green Electricity, and 3-D Printing are Ushering in a Sustainable Era of Distributed Capitalism.* The World Financial Review.

[187] Rifkin, J. (2012*). The Third Industrial Revolution: How the Internet, Green Electricity, and 3-D Printing are Ushering in a Sustainable Era of Distributed Capitalism.* The World Financial Review, p. 9.

Klaus Schwab has a different idea. According to the World Economic Forum (WEF) chief executive officer, there are at least three reasons why we can talk about a fourth industrial revolution. These are speed, scope and impact[188].

First of all, "*the speed of current breakthroughs has no historical precedent. When compared with previous industrial revolutions, the Fourth is evolving at an exponential rather than a linear pace".[189]* Innovations and technologies are getting better faster than anything else ever. These innovations are improving at an exponential rate just as predicted by Gordon Moore, and they will have soon a huge impact on our personal lives, on industrial production processes, on the way work is organized, and on the distribution of income. To understand the actual impact of Moore's law, one has just to compare computers' performance at different times. For example, let's think of "*a $400 iPhone 4 [. It] offers roughly equal performance to the CDC 7600 supercomputer, which was the fastest computer in 1975 and cost $5 million at the time*".[190] These technologies are feeding back on themselves in terms of their ability to improve over time: every technology serves as a base ground for others, leading to an increase in the rate of innovation. Furthermore, with regard to the scope of the phenomenon, the author is of the view that the fourth industrial revolution *"is disrupting almost every industry in every country"*[191] and, therefore, it has a global reach. Finally, the third major factor which could distinguish the fourth industrial revolution from the previous ones is the impact: *"the breadth and depth of these changes herald the transformation of entire systems of production, management, and governance*".[192] For all these reasons, many view the new digital technologies as having the potential to lead to a new Industrial Revolution.

The fourth industrial revolution is commonly referred to as Industry 4.0. The term "Industry 4.0", specifically, is being used to describe the application of the 21st technologies in the manufacturing sector. It was used for the first time at the Hanover Fair which took place in Germany in 2011. In Italy, instead, the term first appeared in 2016 in the

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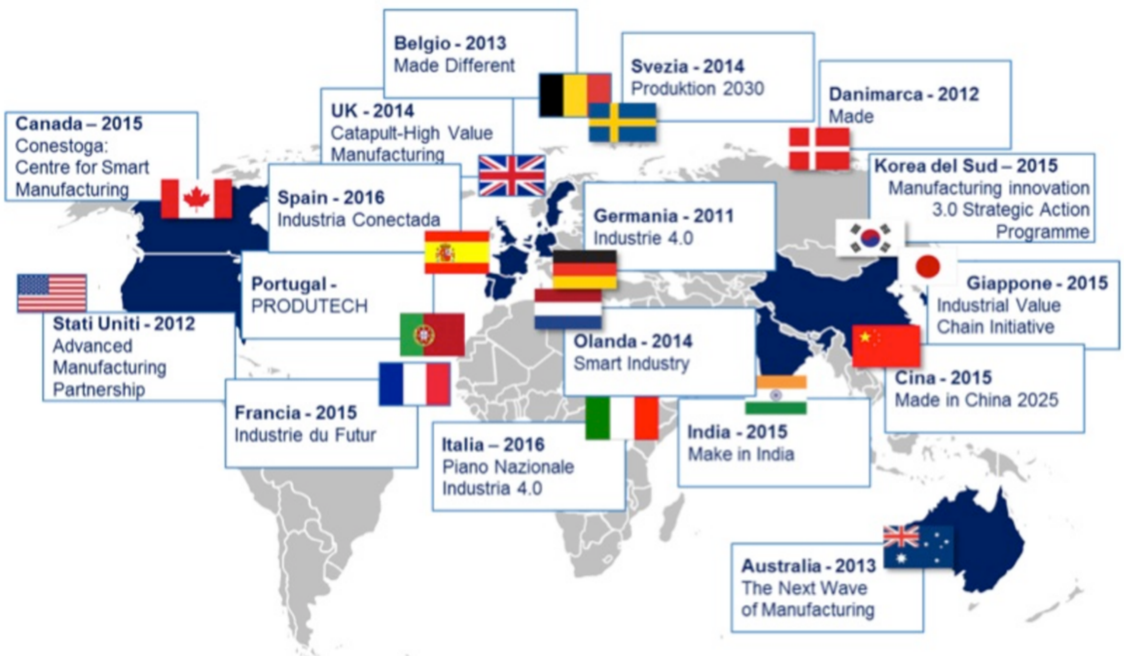
[188] Schwab, K. (2016). La quarta rivoluzione industriale. Milano: FrancoAngeli
[189] Schwab, K. (2016). La quarta rivoluzione industriale. Milano: FrancoAngeli
[190] Manyika, J., Chui, M., Bughin, J., Dobbs, R., Bisson, P. and Marrs, A. (2013). *Disruptive technologies: Advances that will transform life, business, and the global economy*. McKinsey Global Institute Report, p 43.
[191] Schwab, K. (2016). La quarta rivoluzione industriale. Milano: FrancoAngeli
[192] Schwab, K. (2016). La quarta rivoluzione industriale. Milano: FrancoAngeli

"Piano Nazionale Impresa 4.0 2017-2020"[193] document submitted by the Minister of Economic Development, Carlo Calenda.

Many industrialized countries have taken the first step towards the adoption of the Industry 4.0 technologies. Their introduction into production processes is facilitated by country-specific initiatives. There is no one-size-fits-all model, and, consequently, industrial plans and the way these are implemented differ from one country to another[194], as it can be seen from the picture below.



Figure[195]

It is therefore important to refer expressly to the policies adopted by some major countries in this connection. In particular, Germany, Italy, France, United Kingdom and United States of

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194 Magone, A. and Mazali, T. (2016). *Industria 4.0: Uomini e macchine nella fabbrica digitale*. Milano: Guerini.

195 Taisch, M. and De Carolis, A. (2016). *La Quarta Rivoluzione Industriale nel mondo*. [online] Industria Italiana: analisi & news su economia reale, innovazioni, digital transformation. Available at: https://www.industriaitaliana.it/la-quarta-rivoluzione-industriale-nel-mondo/ [Accessed 22 May 2018].

America (USA) policies are considered in more details. These countries can be divided into three groups on the basis of the model used for Industry 4.0[196]:

- The "research-oriented" model: Germany and United States.
- The "enterprise-oriented" model: Italy.
- The mixed model: France and United Kingdom.

Germany is considered to be the precursor of Industry 4.0. Indeed, already in 2011, Germany drew up a national strategic initiative (which was later adopted through the High-Tech Strategy 2020 Action Plan) aimed at enhancing Germany's leading position in manufacturing over the course of 10-15 years. The Industry 4.0 initiative "*aims to drive digital manufacturing forward by increasing digitalisation and the interconnection of products, value chains and business models (…) It supports the integration of cyber physical systems (CPS) and Internet of Things and Services (IOTS) with an eye to enhance productivity, efficiency and flexibility of production processes and thus economic growth*"[197]. The federal government has a central role in defining innovation strategies and funding. However, cooperation with private entities is also important. In 2013, an Industry 4.0 Platform has been created to foster dialogue between the Ministry of Education and Research (BMBF), the Ministry for Economic Affairs and Energy (BMWI), companies providing technology (such as Bosch, Siemens and SAP), industrial associations (BITKOM, VDMA and ZVEI), universities (such as Fraunhofer and the National Academy of Science and Engineer), and research centres. At present, 300 stakeholders which represent 159 private and public bodies form part of this platform. The key point of the Industry 4.0 plan is to provide direct funding for research and development programs and income tax exemption for promoting venture capital investments. Furthermore, the government has promoted an integrated work-linked training projects which enable young people to acquire skills and knowledge required to work in smart factories. The federal government has made available 200 million of euros for these purposes. In general, Germany uses direct financing to companies provided by the

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[196] KPMG (2017). *Industria 4.0 per un'Impresa globale: la dimensione del fenomeno, le implicazioni per il Paese, le policy*. Comitato Leonardo – Italian Quality Committee, pp.15-27.
[197] European Commission (2017). *Germany: Industrie 4.0.* Digital Transformation Monitor, p. 3.

"Kreditanstalt fur Wideraufbau" (KFW) public bank (which is equivalent to the Italian Deposit and Consignment Office) instead of tax concessions[198].

United States of America (USA) adopted a "research-oriented" program as well. But, in contrast to Germany, Industry 4.0 is mainly driven by consortia and private coalitions which bring together ICT enterprises (Intel, Cisco Systems, General Electric and AT&T), manufacturing industries (General Motors and Rockwell Automation) and universities[199]. Among these, the Industrial Internet Consortium (IIC) should be mentioned. It was "*founded by General Electric (...) AT&T, Cisco and IBM, by mid-2016 (...) it seeks to promote innovation through the establishment of uses cases and testbeds to enable rapid testing of ideas and technologies in real-world application (...) [and] it aims to drive development of reference architectures frameworks and open standards required for the interoperability of industrial systems*"[200]. Therefore, the U.S. government plays a minor role in promoting Industry 4.0 in the country. Nevertheless, major initiatives have been taken by the government. In 2011, the Obama administration launched the Advanced Manufacturing Partnership (AMP) which can be defined as a public/private national effort to boost employment by innovating manufacturing industry. It is estimated that the government allocated half a million euro to support investments in science, technology and innovation. Furthermore, in 2012, the U.S. government launched the National Network for Manufacturing Innovation Program (NNMI), also known as "Manufacturing USA" aimed at creating a network of 15 innovation centres (in the form of public-private partnerships) any of which is specialized in a particular technology (one of them is the Digital Manufacturing and Design Innovation Institute or DMDII which is specialized in digital manufacturing and it is based in Chicago, Illinois). Besides carrying out research activities these regional institutes are involved in activities related to the implementation of innovative strategies and assistance for companies[201]. The government provided for a fund of USD 5 billion per year

[198] European Commission (2017). *Germany: Industrie 4.0*. Digital Transformation Monitor.
[199] Magone, A. and Mazali, T. (2016). *Industria 4.0: Uomini e macchine nella fabbrica digitale*. Milano: Guerini, p. 64.
[200] Kagermann, H., Anderl, R., Gausemeier, J., Schuh, G. and Wahlster, W. (2016). *Industrie 4.0 in a Global Context*. Acatec Study, p. 53.
[201] KPMG (2017). *Industria 4.0 per un'Impresa globale: la dimensione del fenomeno, le implicazioni per il Paese, le policy*. Comitato Leonardo – Italian Quality Committee, pp.15-27

until 2024 for this purpose. Moreover, the Department of Energy earmarked extra USD 250 million[202]. However, important differences between the German model and the American one do exist. First, Germany (and Europe in general) focuses on the development of a smart factory whereas United States of America (USA) gives priority to the Internet of Things technology. It follows that the European countries work to optimize manufacturing industry while American research activities are designed to improve the economic system as a whole (in fact, differently from the Germany's "Platform Industry 4.0", the "Industrial Internet Consortium" affects sectors other than manufacturing such as energy and transports)[203]. Secondly, a "*top-down approach to standardisation predominates in Germany*"[204] which, therefore, wants to create a common standard to which companies can refer when developing new technologies whereas United States' approach is more heterogeneous, and it is based on the establishment of platforms for connecting workers together and sharing information. Finally, as stated above, the European model provides for a substantial public intervention whereas the American model is directly supported by private enterprises and research centres[205].

Italy takes a different approach to that of Germany and United States. The Italian Industry 4.0 national plan, in fact, provides for a series of fiscal measures aimed at encouraging the introduction of new technologies into Italian industrial production processes. In particular, the strategy addresses two main subjects. First, it supports the take-up of innovative technologies. Secondly, it seeks to create a highly competent and qualified labour force by means of a series of initiatives such as the Digital Innovation Hubs, I4.0 Competence Centres, education programmes, vocational training, Industrial PhDs related to I4.0[206]. Our educational system, in fact, is unable to adequately prepare people to meet future challenges.

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[202] KPMG (2017). *Industria 4.0 per un'Impresa globale: la dimensione del fenomeno, le implicazioni per il Paese, le policy*. Comitato Leonardo – Italian Quality Committee, p. 21.

[203] Kagermann, H., Anderl, R., Gausemeier, J., Schuh, G. and Wahlster, W. (2016). *Industrie 4.0 in a Global Context*. Acatec Study, p. 53.

[204] Kagermann, H., Anderl, R., Gausemeier, J., Schuh, G. and Wahlster, W. (2016). *Industrie 4.0 in a Global Context*. Acatec Study, p. 37.

[205] Magone, A. and Mazali, T. (2016). *Industria 4.0: Uomini e macchine nella fabbrica digitale*. Milano: Guerini, p. 66.

[206] European Commission (2017). *Italy: "Industria 4.0"*. Digital Transformation Monitor.

The Italian government has made available 18 billion of euros for these purposes. The main actions of the "Piano Nazionale Impresa 4.0 2017-2020"[207] are the following:

- Super- and Hyper-depreciation: the former "*entails a 40% increase in the ordinary depreciation deduction for investments in new industrial machinery, meaning that acquisition costs are raised by an equivalent share for accounting purposes*"[208] whereas the latter "*consists of a 150% increase in the ordinary depreciation deduction*"[209].
- Nuova Sabatini: it provides easier access to credit for businesses purchasing machinery and software.
- SME Guarantee Fund: whose aim is to facilitate access to credit for SMEs by providing them with the granting of public guarantees.
- Tax credit for research and development: "*companies that increase their R&D expenditure in the 2017-2020 period benefit from a 50% tax credit on their additional expenses (incremental credit), with an annual ceiling of 20 million of euros*"[210].
- Patent box: it provides for the introduction of a special fiscal regime that applies to patent, trademarks and design, production processes and information acquired in the industrial domain.
- Start-up and innovative SMEs: such businesses benefit from a special reference framework which include simplify administrative procedures and tax concessions.
- Centres of technology transfer: they provide training and advice services for businesses relating to augmented reality, IOT, additive manufacturing, cybersecurity, big data and cloud technology.

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[207] Ministry of Economic Development (2017). *Incentives to investors: Italy's Industria 4.0 plan*. [online] Investorvisa.mise.gov.it. Available at: https://investorvisa.mise.gov.it/index.php/en/home-en/incentives-to-investors-italy-s-industria-4-0-plan [Accessed 22 May 2018].

[208] Ministry of Economic Development (2017). *Incentives to investors: Italy's Industria 4.0 plan*. [online] Investorvisa.mise.gov.it. Available at: https://investorvisa.mise.gov.it/index.php/en/home-en/incentives-to-investors-italy-s-industria-4-0-plan [Accessed 22 May 2018].

[209] Ministry of Economic Development (2017). *Incentives to investors: Italy's Industria 4.0 plan*. [online] Investorvisa.mise.gov.it. Available at: https://investorvisa.mise.gov.it/index.php/en/home-en/incentives-to-investors-italy-s-industria-4-0-plan [Accessed 22 May 2018].

[210] Ministry of Economic Development (2017). *Incentives to investors: Italy's Industria 4.0 plan*. [online] Investorvisa.mise.gov.it. Available at: https://investorvisa.mise.gov.it/index.php/en/home-en/incentives-to-investors-italy-s-industria-4-0-plan [Accessed 22 May 2018].

- I4.0 Competence Centres: these are groups composed of a research body and at least two enterprises whose aim is to support and train companies on issues relating to Industry 4.0 and to initiate innovative projects.

This approach is known as "enterprise-oriented" because it aims to encourage businesses to invest in the new technologies through fiscal measures. "*The success of the 'Industria 4.0' national plan depends on the extent to which entrepreneurs take advantage of the measures that have been put in place*"[211], as claimed by the Italian minister of Economic Development Carlo Calenda.

In 2015, France launched the "Industrie du Futur" plan to modernise French industries, not only by prompting companies to robotics, big data and augmented reality but also to organisational innovations and new business models. The French national plan comes closer to the Italian plan on issues relating to tax concessions, including super-depreciations and tax credits. However, it also provides for an allocation of funds to cover research and development expenses. The public funding in question amounts to 100 millions of euros. Furthermore, Bipfrance has earmarked 2.2 millions of euros in loans for small and medium sized enterprises (SMEs). Among the research topics identified by the "Alliance Industrie du Futur" plan are new resources, smart cities, eco-mobility, transport, smart devices, and smart food choices[212].

In the same year, United Kingdom promoted the "High Value Manufacturing" action plan to revitalise the manufacturing sector. One objective of the proposed plan was to increase R&D activities. To this end, innovations centres, known as "Catapults", were created. They help businesses to turn commercial ideas into practical solutions. Moreover, "*they bridge the gap between universities and industry, ensuring that high-potential technologies do not fall by the wayside before they can be brought to market (...) The Catapults' other goals include reducing risk of innovation, accelerating the peace of business development and creating sustainable jobs and growth*"[213]. At present, there are seven research centres focusing on

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[211] European Commission (2017). *Italy: "Industria 4.0"*. Digital Transformation Monitor.

[212] KPMG (2017). *Industria 4.0 per un'Impresa globale: la dimensione del fenomeno, le implicazioni per il Paese, le policy*. Comitato Leonardo – Italian Quality Committee, p. 21-23.

[213] Kagermann, H., Anderl, R., Gausemeier, J., Schuh, G. and Wahlster, W. (2016). *Industrie 4.0 in a Global Context*. Acatec Study.

digital manufacturing which are part of the broader "Catapult centres" initiative (which, in turn, consists of ten centres each of which is specialized in a particular field e.g. the Satellite Application focuses on space- and satellite-based products). Furthermore, another important objective of the programme is related to the training of workers. Several training centres have been developed to this end such as the Advanced Manufacturing Research Centre (AMRC) and the Manufacturing Technology Centre. The latter centres aim at offering "*graduate and apprenticeship programmes geared towards tackling the shortage of skilled labour in manufacturing industry*"[214] and obtaining workforce able to respond to the needs and the challenge of the future. The government has made available EUR 70 billion to achieve the objectives of the "High Value Manufacturing" action plan. Furthermore, in 2017, the U.K. government launched the "Building our Industrial Strategy" plan, providing 4.7 billion of pounds to spend in R&D activities up to 2021[215].

Initiatives such as those pursued by France and United Kingdom are close to the R&D incentives set out in the German Industry 4.0 plan. However, they diverge from the German model because they also provide tax reliefs for companies similar to those in place in Italy. In fact, the French government introduced a super-depreciation of 140% whereas United Kingdom provided tax credits on research and development (R&D) expenditures[216]. Therefore, it is possible to say that the French and the British approach is somewhere between that adopted by Italy and Germany. In other words, they are pursuing a "mixed approach" that include both research projects and enterprise tax privileges.

In conclusion, the model for Industry 4.0 varies from country to country. Despite these differences, however, all countries' plans are directed toward a common point: the creation of a cyber-physical system. Therefore, both the European and the American model emphasize the integration of the digital word with the physical word of human begins. Indeed, the objective of Industry 4.0 is to deploy the cyber-physical system to improve production and

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[214] Kagermann, H., Anderl, R., Gausemeier, J., Schuh, G. and Wahlster, W. (2016). *Industrie 4.0 in a Global Context*. Acatec Study, p 60.

[215] KPMG (2017). *Industria 4.0 per un'Impresa globale: la dimensione del fenomeno, le implicazioni per il Paese, le policy*. Comitato Leonardo – Italian Quality Committee, p. 21.

[216] KPMG (2017). *Industria 4.0 per un'Impresa globale: la dimensione del fenomeno, le implicazioni per il Paese, le policy*. Comitato Leonardo – Italian Quality Committee.

distribution processes, not only by making them more efficient and less-costly but also by developing new types of goods and services[217].

In the light of the above, industries are becoming more and more capital-intensive: fixed assets are given more weight while less emphasis is placed on human labour. Therefore, it appears that the cost of labour is no longer a key variable in international competition. Far greater importance surely attaches to the proximity of markets, universities, taxation, political freedom, environmental quality. In this new context, America and Europe can regain their leading role as large industrial producers. On the other hand, China, which made cheap labour its strength, may lose its strategic advantage. China is the second largest economy after USA. In 2014, manufacturing industry accounted for the 43% of the country's gross domestic product (whereas in Germany manufacturing industry accounted for the 31% of GDP). However, just the 60% of Chinese industries make use of cutting edge technologies. All other remaining industries have still not faced the third industrial revolution: "*there are a large numbers of Chinese SMEs in which almost no automation or digitalisation has occurred – indeed, many of them are still only just starting to introduce computer-integrated manufacturing (Industry 3.0)*"[218]. China has long understood that mass and cheap production is not a valid strategy for the future for two reasons: first, low-cost products demand is falling; secondly, Chinese workforce is becoming increasingly scarce and expensive. Competition is changing: the winners will be those that will make the best possible use of Industry 4.0. Therefore, a number of initiatives have been taken by the Chinese government to modernize manufacturing industry. Among these, the "Made in China 2020" strategic initiative merits more specific details. Launched in 2015, the initiative aims at transforming Chinese economy from mass- to high-tech production and making China the leading global manufacturing power no later than 2049. Another objective set out in this strategic initiative concerns the promotion of the green economy and, therefore, the improvement of environmental conditions. In fact, the plan aims to reduce carbon dioxide emissions by 22% in 2020 and by 40% in 2025. Furthermore, China aims at becoming self-sufficient in terms of technological

[217] Magone, A. and Mazali, T. (2016). *Industria 4.0: Uomini e macchine nella fabbrica digitale*. Milano: Guerini, p. 66.

[218] Kagermann, H., Anderl, R., Gausemeier, J., Schuh, G. and Wahlster, W. (2016). *Industrie 4.0 in a Global Context*. Acatec Study, p.42.

resources supply. The government has made available significant funding to ensure the achievement of these objectives: these amount to USD 1.090 billions. The majority of government funding has been directed at research and development activities. The research topics identified by the strategic plan are information technologies, robotics, eco-mobility, electrical and medical equipment, biology, and agricultural machinery. Germany is not only China's biggest trade partner but also his "*partner of choice for the implementation of its Made in China 2025 strategy*"[219]. In 2015, the Federal Minister for Economic Affairs and Energy (BMWi), Sigmar Gabriel, and the Chinese Minister of Industry and Information Technology (MIIT), Miao Wei, signed an agreement for the joint development of Industry 4.0. Both countries benefit from this partnership. On one hand, China can acquire the technological know-how needed for the industrial development of the country. Germany, in turn, can raise its export volume and it "*can take advantage of the Chinese market's speed and strength in terms of implementation to test and further develop their Industrie 4.0 solutions*"[220]. However, there are a number of risks concerning data protection, loss of knowledge and software piracy[221].

3.2 The impact of Industry 4.0 on employment levels

The introduction of new technologies into production processes has always been seen as a possible cause of the "*technological unemployment*"[222]. Following recent technological developments, the debate regarding the impact of technological progress on employment levels has been reopened. "*Since the beginning of the 21st century, we have been experiencing a digital transformation – changes associated with innovation in the field of digital*

[219] Kagermann, H., Anderl, R., Gausemeier, J., Schuh, G. and Wahlster, W. (2016). *Industrie 4.0 in a Global Context*. Acatec Study, p.42.
[220] Kagermann, H., Anderl, R., Gausemeier, J., Schuh, G. and Wahlster, W. (2016). *Industrie 4.0 in a Global Context*. Acatec Study, p.43.
[221] Kagermann, H., Anderl, R., Gausemeier, J., Schuh, G. and Wahlster, W. (2016). *Industrie 4.0 in a Global Context*. Acatec Study, pp. 41-45.
[222] Keynes, J. (1931). *Essays in persuasion*. London: Macmillan, pp.321-334.

technology in all aspects of society and economy".[223] Big data, artificial intelligence, 3D printing, augmented reality are the symbols of the current fourth industrial revolution. To analyze the employment impact of the 21st century technologies, several studies have been conducted. Various economists and consulting companies have tried to estimate the expected job gains and losses arising from the introduction of Industry 4.0 technologies into production processes.

Oxford university researchers Carl Benedikt Frey and Michael A. Osborne conducted a study to examine what implications the new wave of technological innovations will have for the employment situation. For the purpose of this analysis, they examined 702 job positions (derived from O*NET data) by classifying them depending on the probability of being automated. Three employment categories were identified: at high-, medium- and low-risk of automation. Data from the analysis showed that "*47 percent of total US employment is in the high-risk category, meaning that associated occupations are potentially automatable over some unspecified numbers of years, perhaps a decade or two*"[224]. Employment is expected to increase in the management, healthcare, and education sectors. Conversely, production, transportation, and logistics sectors (which belong to the high-risk of automation category) will see their labour demand to drop. This will inevitably change the technical knowledge and skills required at work. Among these, problem solving, critical thinking and creativity will be the most important and popular. Frey and Osbornes' research will be analysed in more details in the following chapter.

The Organisation for Economic Cooperation and Development (OECD) economists took Frey and Osborne's model as a benchmark for their analysis relating to the employment impact of technological progress. The occupation-based approach followed by Frey and Osborne tends to overestimate the number of jobs at risk of automation since many high-risk occupations contains tasks that cannot be automated considering the current state of technology. For example, many salespeople are involved in activities requiring face-to-face

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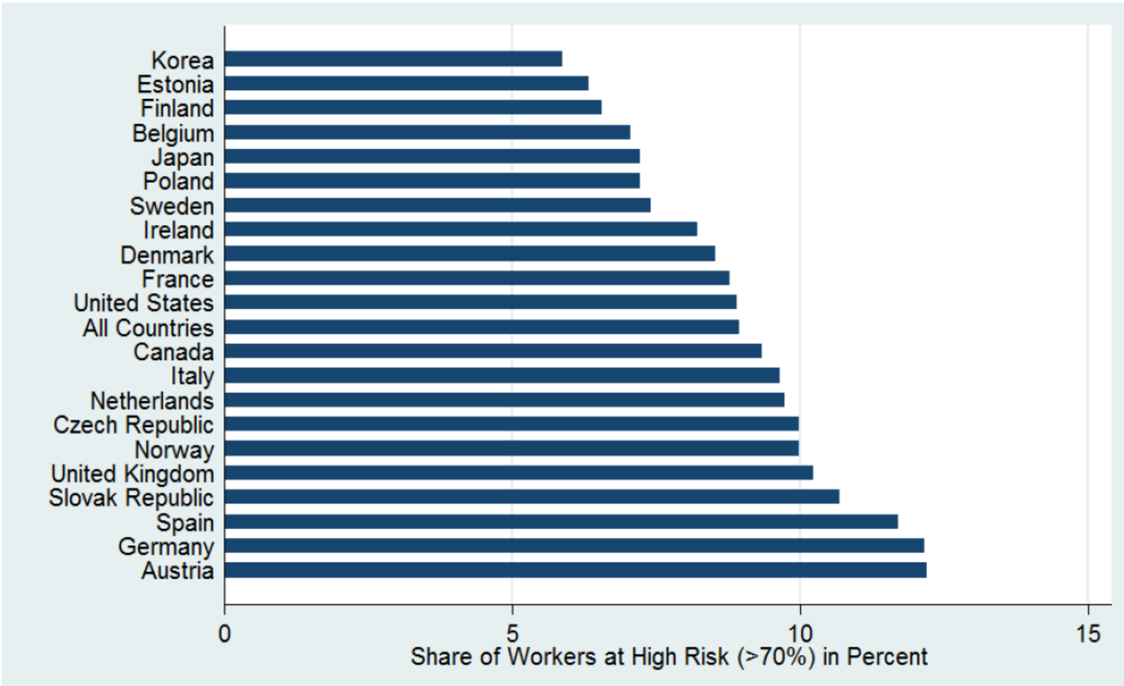
[223] Acemoglu, D. and Restrepo, P. (2017). *Robots and Jobs: Evidence from US Labor Markets*. SSRN Electronic Journal, p. 7.

[224] Frey, C. and Osborne, M. (2013). *The future of employment: How susceptible are jobs to computerization?*. Technological Forecasting and Social Change, 114, p. 38.

interaction which is still difficult to automate; therefore, even if Frey and Osborne estimated that the 92% of people employed in the "retail salesperson" occupational category is at high-risk of automation, actually the percentage is lower.[225] Then, the study wrongly assumes that work activities within the same occupational group are similar, without taking into account the fact that these are extremely varied, and they differ even between countries. As a consequence of that, the OECD economists decided to use a task-based approach. In carrying out this examination, the economists relied upon the Programme for the International Assessment of Adult Competences (PIAAC). Compared to the O*NET database which provides information on occupational activities, the PIAAC provides detailed descriptions of each workplaces task. Then, through a probabilistic classification algorithm, they matched variables describing "*engineers bottlenecks*"[226] with those describing workplace activities to estimate their automation potential. Subsequently, by grouping activities according to the occupational category to which they belong, it was possible to estimate what occupations and how many workers are at risk of automation. The "*task-based approach results in a much lower risk of automation compared to the occupation-based approach*"[227]. In fact, if Frey and Osborne's model concluded that 47% of the American workforce is at risk of automation, the OECD economists actually found that in the United States only the 9% of employment is at risk. Besides America, other 20 OECD countries are taken into account in the analysis. They are listed in table below which also shows the :

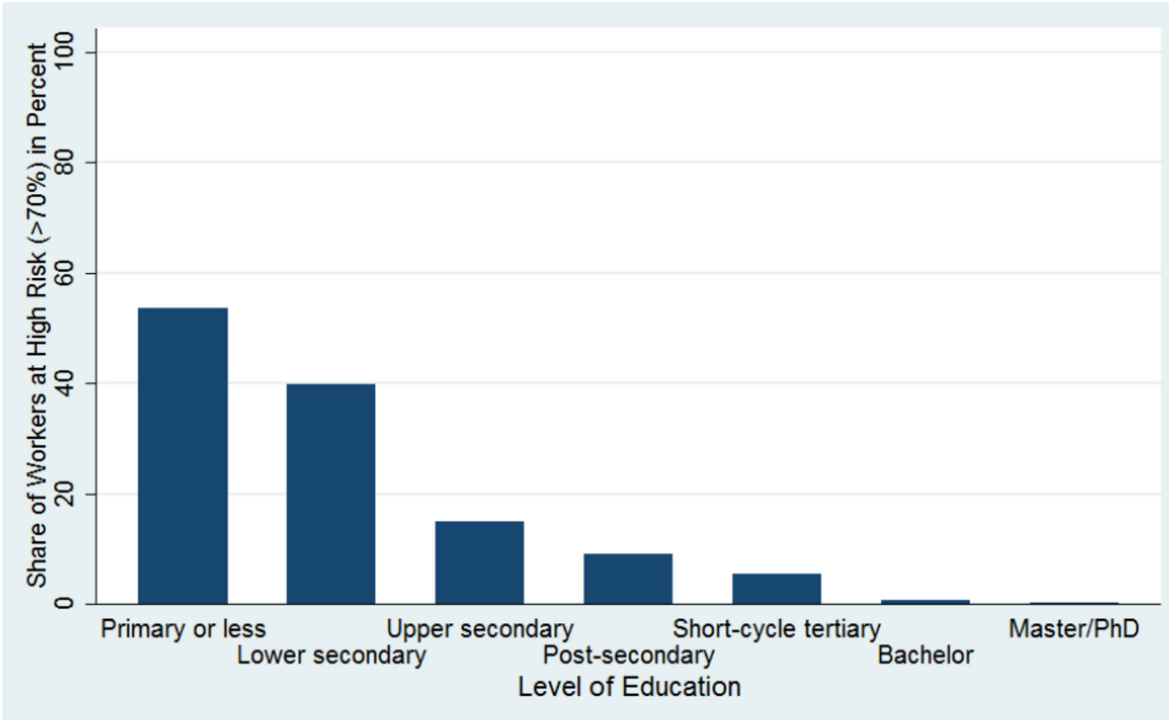
[225] Arntz, M., Gregory, T. and Zierahn, U. (2016). *The Risk of Automation for Jobs in OECD Countries A COMPARATIVE ANALYSIS*. OECD Social, Employment and Migration Working Papers, (189).
[226] Frey, C. and Osborne, M. (2013). *The future of employment: How susceptible are jobs to computerisation?*. Technological Forecasting and Social Change, 114.
[227] Arntz, M., Gregory, T. and Zierahn, U. (2016). *The Risk of Automation for Jobs in OECD Countries A COMPARATIVE ANALYSIS*. OECD Social, Employment and Migration Working Papers, (189).



Figure[228]

On the y-axis is the 21 OECD countries, on the x-axis if the percentage number of workers belonging to the high-risk category of automation. The automation potential is diverse within the targeted countries. What the report also shows is that automatability and skills are negatively correlated: the higher the skills required at work the lower the risk of automation. This is shown in the picture below. On the y-axis is percentage number of workers at risk of automation, on the x-axis is the educational level.

[228] Arntz, M., Gregory, T. and Zierahn, U. (2016). *The Risk of Automation for Jobs in OECD Countries A COMPARATIVE ANALYSIS*. OECD Social, Employment and Migration Working Papers, (189), p 16.



Figure[229]

The World Economic Forum (WEF) economists take a negative view regarding the employment impact of the next-generation technologies. According to them, Industry 4.0 technologies will exert a very negative and dangerous influence on employment levels. In the report "*The future of jobs: employment, Skills and Workforce Strategy for the Fourth Industrial Revolution*"[230], the World Economic Forum economists seek to estimate the expected employment changes over the period 2015-2025 based on the forecasts of the human resources managers of the world's leading companies. The latter employ more than 13 million workers who represent the 65% of the total workforce. The report concludes that the introduction of the new 21st technologies will lead to "*a net employment impact of more than 5.1 million jobs lost to disruptive labour market changes*

[229] Arntz, M., Gregory, T. and Zierahn, U. (2016). *The Risk of Automation for Jobs in OECD Countries A COMPARATIVE ANALYSIS.* OECD Social, Employment and Migration Working Papers, (189), p 21.
[230] World Economic Forum (2016). *The Future of Jobs Employment, Skills and Workforce Strategy for the Fourth Industrial Revolution*. Global Challenge Insight Report, p. 13.

over the period 2015-2010, with a total loss of 7.1 million jobs (...) and a total gain of 2 million jobs, in several smaller job families"[231]. Therefore, robots will take on 5 million of jobs that were previously carried out by humans in 15 countries around the world. Employment is expected to increase in the business and financial operations, management, computer, mathematical and engineering sectors. Office and administrative, manufacturing, production and the entertainment sectors, instead, will see their labour demand to drop as a result of technological advancements. As a consequence of that, the type of skills required at work will change. The WEF economists believes that instead of completely replacing certain categories of workers in the performance of their activities, machines "*are likely to substitute specific tasks previously carried out as part of these jobs, freeing workers up to focus on new tasks and leading to rapidly changing core skill sets in these occupations*" [232]. Even workers not at risk of automation will have to develop new skills and competences since labour market dynamics will change. The educational system needs to adapt accordingly by forecasting what skills are going to be valuable in the future: human resource managers expected that "*more than a third of the desired core skill sets of most occupations will be comprised of skills that are not yet considered crucial to the job today*"[233]. Furthermore, it is estimated that almost 50% of the hard skills learned during the first years of university become outdated at the end of studies. Therefore, the new workforce is unable to meet businesses demand (nearly 35% of employers find it difficult to fill job vacancies). Not only the educational system has to change but also business have to invest in re-skilling and up-skilling programs. Beside technical knowledge, it is necessary for workers develop a diversified set of soft-skills, including critical thinking, reasoning and active learning, and emotional intelligence[234].

Compared to the pessimistic assumptions previously discussed, Roland Berger economists believe that the introduction of Industry 4.0 technologies into production processes will lead

[231] World Economic Forum (2016). *The Future of Jobs Employment, Skills and Workforce Strategy for the Fourth Industrial Revolution*. Global Challenge Insight Report, p. 13.

[232] World Economic Forum (2016). *The Future of Jobs Employment, Skills and Workforce Strategy for the Fourth Industrial Revolution*. Global Challenge Insight Report, pp. 19-26.

[233] World Economic Forum (2016). *The Future of Jobs Employment, Skills and Workforce Strategy for the Fourth Industrial Revolution*. Global Challenge Insight Report, p. 21.

[234] World Economic Forum (2016). *The Future of Jobs Employment, Skills and Workforce Strategy for the Fourth Industrial Revolution*. Global Challenge Insight Report, pp. 19-26.

to the creation of about 10 million jobs no later than the 2030. In other words, the German consulting company estimated that industrial workforce will increase from 25 billion in 2011 to 35 billion in 2030. "*Around three million of these jobs would be created in manufacturing with the remaining seven million coming in new services*"[235]. Employment growth in manufacturing industry (+1.1 million jobs) will be achieved mainly via the re-localization in Europe of activities previously outsourced to foreign countries[236]. Over the last twenty years, manufacturing industry, in fact, has transferred the 40% of its production to emerging countries in order to exploit the low-cost labour. However, industries can make up ground and bring manufacturing production home through the digitalization of production processes. In fact, "a*s production becomes more capital intensive, the labour cost advantages of traditional low-cost locations will shrink, making it attractive for manufacturers to bring previously offshored jobs back home*"[237]. In other words, the more capital is used in production processes, the less the labour factor will impact on total production costs. Therefore, it will no longer be considered as a determining factor in the choices of location. Furthermore, in-house production will allow companies to reduce logistics costs as well by bringing production closer to the final consumer. Many European countries are already moving in this direction. In particular, one of the aims of the "Horizon 2020" research program funded by the European Commission consists precisely in restoring manufacturing industry by repatriating in Europe enterprises that have moved out their activities elsewhere[238]: the "*Europe Commission [has] set the goal of boosting manufacturing's share of GDP in Europe from 15% to 20% by 2020*"[239]. However, the European deindustrialization and delocalization processes are expected to continue until 2035, reducing the number of people employed by 2.7 million. A similar loss will come from productivity gains achieved by means of the new technologies: in fact, as productivity increases the number of workers

[235] Roland Berger (2016). *The Industry 4.0 transition quantified: How the fourth industrial revolution is reshuffling the economic, social and industrial mode*. Roland Berger GMBH, p. 17.
[236] Roland Berger (2016). *The Industry 4.0 transition quantified: How the fourth industrial revolution is reshuffling the economic, social and industrial mode*. Roland Berger GMBH.
[237] Lorenz, M., Rüßmann, M., Strack, R., Lueth, K. and Bolle, M. (2015). *Man and Machine in Industry 4.0 How Will Technology Transform the Industrial Workforce Through 2025*?. Boston Consulting Group, p. 3.
[238]
[239] Roland Berger (2014). *INDUSTRY 4.0 The new industrial revolution How Europe will succeed*. Roland Berger Strategy Consultants, p. 15.

needed to achieve a given level of output will decreases. To this figure a loss of 2.9 million jobs should be added, considering that human labour will be replaced with machines in the most automatable jobs. In conclusion, the total net effect is positive: 10 million jobs will be created in the face of the 8.4 million that will be destroyed. Therefore, this will result in the creation of about 1.6 million new jobs.[240]

Daron Acemoglu and Pascual Restrepo conducted a study to examine the real-world impact of the robot usage on U.S. employment and wages levels over the period 1990-2007. For the purpose of this analysis, the authors used a "*simple model where robots and workers compete in the production of different tasks*"[241]. Their estimates suggest that as robots usage increase, employment and wages levels fall: in fact, "*the introduction of a new robot per 1.000 workers in a commuting zone reduced the local employment-to-population ratio by 0.37 percentage points and local wages by 0.73%. This is equivalent to 6.2 workers losing their jobs for every robot"*[242]. These data were calculated for a closed economy. In an open economy, it was estimated that robotization has a less, though important, impact on employment and wages: in the latter case, in fact, each robot would cause employment to decrease by 0.34 percentage points and wages by 0.5 percentage point. At present, the number of robots existing in the American economy is extremely small, and, therefore, "*the number of jobs lost due to robots has been limited to between 360,000 and 670,000 jobs*"[243]. However, the industrial application of these "*automatically controlled, reprogrammable, and multipurpose*"[244] machines is expected to grow at sustained peace. In particular, the Boston Consulting Group (BCG) considers two different scenarios for the increase in the percentage of robots used in production processes over the next decade. In the worst-base scenario, "*the world stock of robots will quadruple by 2025. This would correspond to 5.25 more robots per thousand workers in the United States, and (...) it would lead to a 0.90-1.76 percentage points lower*

[240] Roland Berger (2016). *The Industry 4.0 transition quantified: How the fourth industrial revolution is reshuffling the economic, social and industrial mode*. Roland Berger GMBH.
[241] Acemoglu, D. and Restrepo, P. (2017). *Robots and Jobs: Evidence from US Labor Markets*. SSRN Electronic Journal, p. 2.
[242] Acemoğlu, D. and Restrepo, P. (2017). Robots and jobs: Evidence from the US. *VOX CEPR's Policy Portal*. [online] Available at: https://voxeu.org/article/robots-and-jobs-evidence-us [Accessed 15 May 2018].
[242] International Federation of Robotics (2014) World Robotics: Industrial Robots.
[243] Acemoğlu, D. and Restrepo, P. (2017). Robots and jobs: Evidence from the US. *VOX CEPR's Policy Portal*. [online] Available at: https://voxeu.org/article/robots-and-jobs-evidence-us [Accessed 15 May 2018].
[244] International Federation of Robotics (2014) World Robotics: Industrial Robots.

employment to population ratio and 1.3-2.6 percent lower wage growth between 2015 and 2025"[245], as claimed by Daron Acemoglu and Pascual Restrepo. In the best-case scenario, conversely, it is estimated that the spread of robot will triple leading to an employment reduction of 0.54-1 percentage point and a wage reduction of 0.75-1.5 percent point. What the report also shows is that robots industrial usage has a negative effect on employment levels regardless the sector, even though manufacturing industry is the worst affected. Furthermore, within each industry, routine and white-collar workers (such as assembly line workers, train drivers, transport workers) are those who suffer the greatest losses since they perform jobs that are more easily exposed to the risk of automation. Conversely, managers and non-routine workers, in general, are the least affected by the substitution effect arising from the introduction of robots into production processes.

More and more robots are going to be used in production processes in the near future, leading to the substitution of human labour with machines. Even today, we are witnessing the birth of new factory systems with no human component. Therefore, the "*dehumanized factory*"[246] is no more a utopia. For example, the Chinese province of Guangdong has recently launched the "Robot replace human" investment plan to tackle the problem of an increasingly expensive and scarce workforce. The provincial government has made available 135,5 billion of euros for the purpose of encouraging companies to substitute workers for robots in the assembly lines. The Chinese "Changing Precision Technology" Company (which produces components for mobile telephones) is a prime example of factory where human component is practically absent. In fact, it has reduced the number of workers from 650 to 20. Most activities of the plant in question are now performed by robots and sixty mechanical arms. The remaining employees have the task of monitoring the operations carried out by machines. Robots industrial usage allowed for reducing manufacturing defects from 25% to 5% and

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[245] Acemoglu, D. and Restrepo, P. (2017). *Robots and Jobs: Evidence from US Labor Markets*. SSRN Electronic Journal, p. 36.

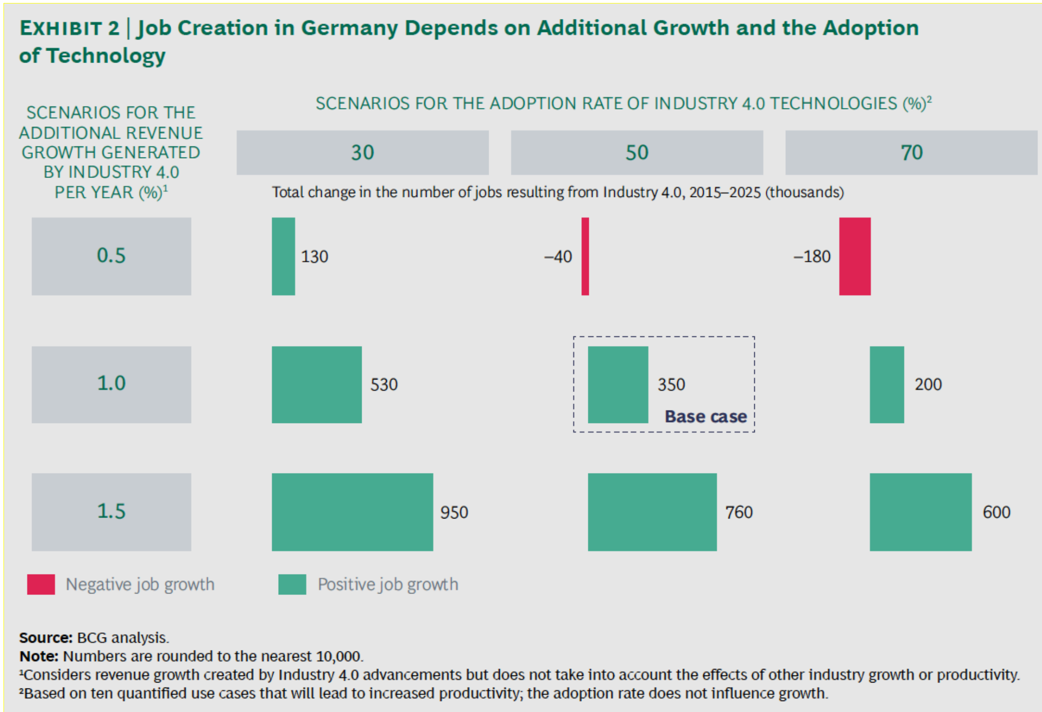
[246] Agostini, S. (2015). *Cina, robot al posto dei lavoratori per rispondere all'aumento dei salari - Il Fatto Quotidiano*. [online] Il Fatto Quotidiano. Available at: https://www.ilfattoquotidiano.it/2015/09/04/cina-robot-al-posto-dei-lavoratori-per-rispondere-allaumento-dei-salari/2006855/ [Accessed 2 Jun. 2018].

increasing production from 8.000 to 21.000 pieces. But this is only a first step of a broader strategy to robotize production processes.[247]

In 2015, the Boston Consulting Group (BCG) published a report whose aim was to "*understand how the industrial workforce will evolve with Industry 4.0 [by looking at] the effect that these new technologies will have on Germany's manufacturing landscape, which is among the world's most famous advanced*"[248]. To do so, the Boston Consulting Group economists worked together with twenty industrial experts to forecast the impact that each of the ten selected technologies (for example self-driving cars, big data, robots, augmented reality, additive manufacturing) will have on employment. The study does not seek to estimate the change on overall employment brought about by the technologies of Industry 4.0 (since at present is not possible to forecast what jobs will be created in the future) but only the incremental one. Furthermore, Germany is the only country that is taken into account in this analysis. Several scenarios were analysed by considering two variables: the additional revenue growth generated by Industry 4.0 per year and their degree of adoption. In general, the Boston Consulting Group economists take a positive view of the employment impact of Industry 4.0 and they believe that more jobs will be created than those lost. The figure below illustrates this argument:

[247] Agostini, S. (2015). *Cina, robot al posto dei lavoratori per rispondere all'aumento dei salari - Il Fatto Quotidiano*. [online] Il Fatto Quotidiano. Available at: https://www.ilfattoquotidiano.it/2015/09/04/cina-robot-al-posto-dei-lavoratori-per-rispondere-allaumento-dei-salari/2006855/ [Accessed 2 Jun. 2018].

[248] Lorenz, M., Rüßmann, M., Strack, R., Lueth, K. and Bolle, M. (2015). *Man and Machine in Industry 4.0 How Will Technology Transform the Industrial Workforce Through 2025*?. Boston Consulting Group, p. 3.



Figure[249]

As can be seen from the graph above, in the majority of scenarios, the number of jobs lost will be offset by the number of those that will be created following the introduction of the new 4.0 technologies into production processes. Let's consider, for example, the most likely scenario in which Germany will use the new technologies of "*Industry 4.0 to generate additional revenue growth of 1 percent per year and that the adoption rate of these technological advancements would be 50 percent*".[250] In this case, Industry 4.0 will lead to the creation of 350,000 jobs. "*A greater use of robotics and computerization will reduce the number of jobs in assembly and production by approximately 610,000. However, this decline will be more than offset by the creation of approximately 960,000 new jobs*"[251]. Employment

[249] Lorenz, M., Rüßmann, M., Strack, R., Lueth, K. and Bolle, M. (2015). *Man and Machine in Industry 4.0 How Will Technology Transform the Industrial Workforce Through 2025*?. Boston Consulting Group, p. 7.
[250] Lorenz, M., Rüßmann, M., Strack, R., Lueth, K. and Bolle, M. (2015). *Man and Machine in Industry 4.0 How Will Technology Transform the Industrial Workforce Through 2025*?. Boston Consulting Group, p. 7.
[251] Lorenz, M., Rüßmann, M., Strack, R., Lueth, K. and Bolle, M. (2015). *Man and Machine in Industry 4.0 How Will Technology Transform the Industrial Workforce Through 2025*?. Boston Consulting Group, p. 8.

will decrease mainly in the assembly and production sectors as these involve repetitive tasks that are easily replaceable by machines. But also, employment in routine cognitive activities is expected to decrease as artificial intelligence performance improves. Conversely, data science, IT, R&D are in the list of sectors which will stand to benefit from technological revolution. As regard the type of skills required by industries, it seems clear that both hard skills (IT competencies, programming, analytic skills) and soft skills such as problem-solving and creativity will play an important role in the "*race against the machines*"[252].

A different outcome comes from the McKinsey Global Institute's analysis. In carrying out this examination the McKinsey economists used a methodology which is similar to that of Carl Benedikt Frey and Michael A. Osborne. They used O*NET (2014) and the World Bank data "*to break down about 800 occupations into more than 2.000 activities*"[253]. In turn, the economists tried to determine the skills required to perform these activities. In particular, 18 critical competences were identified. The latter were grouped in five categories: sensory perception, cognitive capabilities, natural language processing, social and emotional capabilities and physical capabilities. Then, McKinsey economists compared computer performance with human performance with respect to the capabilities identified. In this way it was possible to "*assess the state of technology today and the potential to automate work activities in all sectors of the economy by adapting currently demonstrated technologies*"[254]. At the moment, technologies are equivalent to men in planning, information retrieval and motor skills (which, therefore, belong to the "top quintile" category). Conversely, creativity, problem solving, and social emotions skills cannot be automated yet considering the current state of technologies. Technologies' performance is below the human level with respect to these capabilities.

This is shown in the picture below:

[252] Brynjolfsson, E. and McAfee, A. (2011). *Race against the machine: how the digital revolution is accelerating innovation, driving productivity, and irreversibly transforming employment and the economy*. Lexington, Massachusetts: Digital Frontier Press

[253] McKinsey (2017). *A future that works: automation, employment and productivity*. New York: McKinsey Global Institute, p. 130.

[254] McKinsey (2017). *A future that works: automation, employment and productivity*. New York: McKinsey Global Institute, p. 46.

Below median | Median | Top quartile

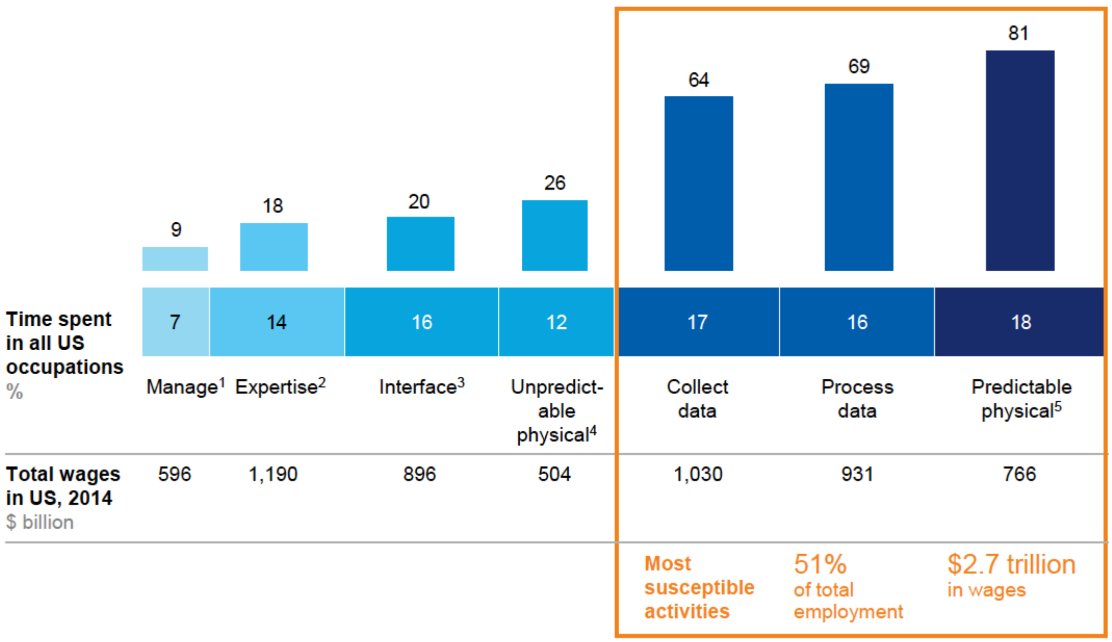
	Automation capability	Capability level[1]	Description (ability to ...)
Sensory perception	Sensory perception	Median	Autonomously infer and integrate complex external perception using sensors
Cognitive capabilities	Recognizing known patterns/categories (supervised learning)	Top quartile	Recognize simple/complex known patterns and categories other than sensory perception
	Generating novel patterns/ categories	Below median	Create and recognize new patterns/categories (e.g., hypothesized categories)
	Logical reasoning/ problem solving	Below median	Solve problems in an organized way using contextual information and increasingly complex input variables other than optimization and planning
	Optimization and planning	Top quartile	Optimize and plan for objective outcomes across various constraints
	Creativity	Below median	Create diverse and novel ideas, or novel combinations of ideas
	Information retrieval	Top quartile	Search and retrieve information from a large scale of sources (breadth, depth, and degree of integration)
	Coordination with multiple agents	Below median	Interact with others, including humans, to coordinate group activity
	Output articulation/ presentation	Median	Deliver outputs/visualizations across a variety of mediums other than natural language
Natural language processing	Natural language generation	Median	Deliver messages in natural language, including nuanced human interaction and some quasi language (e.g., gestures)
	Natural language understanding	Below median	Comprehend language, including nuanced human interaction
Social and emotional capabilities	Social and emotional sensing	Below median	Identify social and emotional state
	Social and emotional reasoning	Below median	Accurately draw conclusions about social and emotional state, and determine appropriate response/action
	Social and emotional output	Below median	Produce emotionally appropriate output (e.g., speech, body language)
Physical capabilities	Fine motor skills/dexterity	Median	Manipulate objects with dexterity and sensitivity
	Gross motor skills	Top quartile	Move objects with multidimensional motor skills
	Navigation	Top quartile	Autonomously navigate in various environments
	Mobility	Below median	Move within and across various environments and terrain

Figure[255]

Initially, the analysis concerned only the United States of America (USA). Subsequently, the same methodology was adopted for the global economy. In total, 46 countries were taken into consideration. The consulting company estimated that the 46% of jobs in United States

[255] McKinsey (2017). *A future that works: automation, employment and productivity*. New York: McKinsey Global Institute, p. 45.

of America have the potential to be automated. This proportion increases to 49% if we consider the global economy as a whole. Furthermore, the economists selected 7 out of 2000 activities in which men spend the most of their working time to examine the degree to which they can be automated. These activities are shown in the picture below:

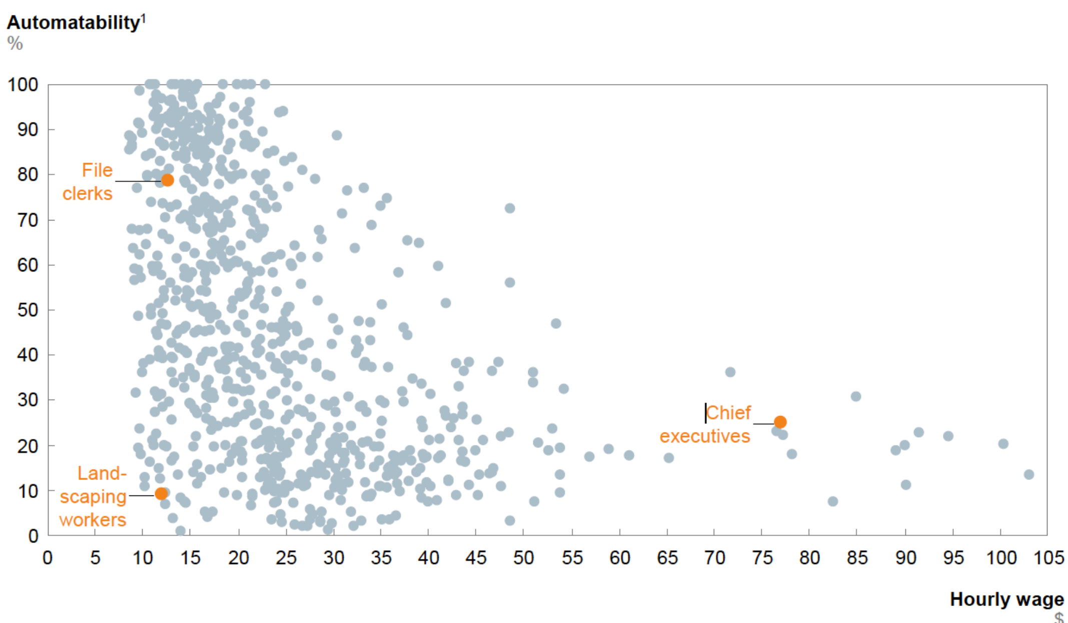


Figure[256]

Physical activities (relating to the manufacturing and agricultural sectors) as well as those concerning collecting and processing data (which can be founded mainly in the finance and insurance sectors) suffer from a relatively high risk of automation by considering the current state of technology. The latter activities employ about 51% of the working population which, therefore, is exposed to a high-risk of being replaced with technologies in the performance of these tasks. Whereas unpredictable physical, interface, expertise and manage activities have a lower risk of automation compared to those mentioned previously. Moreover, the countries with the highest automation potential appeared to be China, India, Japan, United

[256] McKinsey (2017). *A future that works: automation, employment and productivity*. New York: McKinsey Global Institute, p. 52.

States of America and some European nations (in particular, Germany, Italy, France and United Kingdom). Even if the new wave of technological progress is likely to create unemployment, significant productivity gains will be achieved. In fact, even if the number of people employed is expected to fall by 1.1 billion as a result of the introduction of 4.0 technologies into production processes, automation will increase productivity of about 0.8-1.4%. The McKinsey economists also analysed how technological progress will affect the workforce composition by assessing its impact on wages. The report shows the existence of a negative correlation between technical automation potential and wage levels, even if some exceptions to this statement exists. In general, the higher the risk of automation, the lower the salary will be. This situation is depicted in the picture below:



Figure[257]

On the y-axis is the automation potential, on the x-axis is the hourly wage. As show in the figure above, low-skilled and low-wages workers are the most exposed to the risk of automation. McKinsey analysis, therefore, seems to support the skill-biased technical change

[257] McKinsey (2017). *A future that works: automation, employment and productivity*. New York: McKinsey Global Institute, p. 49.

hypothesis as low-skilled occupations are more at risk of automation compared to high- and medium-skilled ones. What the report also shows is that technologies will be able to automate only small parts of activities. According to McKinsey economists, in fact, only 5% of the 830 occupations examined can be fully automated and, therefore, carried out by the machines[258]. For example, let's consider the work carried out by a retail salesperson. The latter must possess social as well as cognitive capabilities to interact with customers and respond to their requests. Moreover, physical abilities are also required in the performance of this job since, for example, the salesperson has to take goods from the shelves. Nowadays, there is no technology that is able to perform all these functions. Since many work activities require a diversified set of skills, it follows that just few occupations can be entirely performed by machines.

Furthermore, the McKinsey Global Institute tried to estimate the date in which the "high-risk" occupations will be automated. To do that, they "*identified five factors that can influence the pace and extent of automation of working activities. They are: technical feasibility, the cost of developing and deploying solutions, labour market dynamics, economic benefits and social and regulatory acceptance*"[259]. In turn, these factors were grouped into four stages relating to the development and the adoption of a new technology. They are: technical automation potential, solution development, economic feasibility and adoption. A technology must go through all these stages in order to be adopted in production processes. Therefore, the time it takes to proceed through these stages determines the pace at which activities will be automated. Different methods are used to estimate the timing of each of these development phases. For example, to estimate the timing of the "technical automation potential" stage, the McKinsey economists relied on interviews and surveys with academics and industrialists whereas for the "economic feasibility" phase they compared wages evolution estimates with those concerning technology cost reductions. Moreover, to estimate the timing of the "solution development" and the "adoption" phase the economists looked at historical precedents. Two scenarios were considered for each of these phases: one

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[258] McKinsey (2017). *A future that works: automation, employment and productivity*. New York: McKinsey Global Institute.

[259] McKinsey (2017). *A future that works: automation, employment and productivity*. New York: McKinsey Global Institute, p. 79.

in which the development and adoption of a new technology is more rapid and another in which timing is slower. The analysis showed that in the earliest scenario, occupations belonging to the high-risk category of automation will be computerized in 2035 whereas in the latest scenario this will occur no earlier than the 2075.[260]

In general, there is no convergence of view among economists regarding the employment impact of the 21st technologies. Therefore, it is not possible to forecast the impact of the "fourth industrial revolution" on labour market dynamics. Economists have quite different opinions on what the effects deriving from the introduction of new technologies will be. Someone says that new jobs will be created, others claim that many jobs will be destroyed as a consequence of the introduction of the next-generation technologies into production processes. However, all studies agree that technological progress will profoundly affect workforce composition.

3.3 Frey and Osborne's studies: the future of employment

The phenomenon of the routine-biased technical change has been extensively analysed in the previous chapter. According to this train of thoughts, technological progress replaces workers in carrying out routine tasks. Conversely, non-routine tasks, either cognitive and manual, cannot be encoded and, therefore, automated. Nowadays, things have changes: 4.0 technologies are apparently able to perform non-routine activities as well. In particular, the technological progresses that have been recently achieved in the field of machine learning (ML) allowed for automating non-routine cognitive tasks whereas the advanced mobile robotics (MR) has proved to be able to take on non-routine manual works that previously were performed by men. In 2004, Levy and Murnane argued that it would be impossible to automate the driving of a vehicle, given the difficulty of replicating human perception. They claimed that: "*as the driver makes his left turn against traffic, he confronts a wall of images*

[260] McKinsey (2017). *A future that works: automation, employment and productivity*. New York: McKinsey Global Institute.

and sounds generated by oncoming cars, traffic lights, storefronts, billboards, trees, and a traffic policeman (…) The truck driver [has] the schema to recognize what [he is] confronting. But articulating this knowledge and embedding it in software for all but highly structured situations are at present enormously difficult tasks (…) Computers cannot easily substitute for humans in [jobs like driving]".[261] Six years later, however, Google created the first self-driving car. This is just one example to understand that the ability of machinery is improving considerably. Soon, automation will be able to enter into the "non-routine" domain as well. As a consequence of that, many workers may lose their jobs. For example, let's think of the possibility of replacing millions of drivers working in the transport sector with Google's self-driving car. Nowadays, we are already seeing human/machines substitution in manual non-routine activities. An example of this is offered by Amazon's "*Kiva*" robots which have replaced millions of storekeepers (about 90% of the human labour force) in Lupton's warehouse[262]. Automation is not only able to reduce labour costs, but it is also more efficient than the human workforce. According to the vice president of Amazon, David Clark, robot usage reduces the company's operating expenses by about 20% and logistic costs by about $ 22 million. If automation is extended to all the company's distribution centres, $ 2.5 millions of operational expenditure will be saved[263]. New technologies are able to perform not only manual non-routine tasks (such as driving a vehicle), but also non-routine cognitive activities. In 1996, Polanyi stated that "*we know more than we can tell*"[264] alluding to the impossibility of codifying human cognition. Nowadays, however, technological progress seems to have denied the so-called Polanyi's paradox. According to the McKinsey Global Institute, "*we are living in a new automation age in which robots and computers can not only perform a range of routine physical work activities better and more cheaply than humans but are also increasingly capable of accomplishing activities that include cognitive capabilities. These include making tacit judgements, sensing emotion,*

[261] Levy, F. and Murnane, R. (2004). *The New Division of Labor: How Computers are Creating the Next Job Market*. Princeton: Princeton University Press, p. 28.
[262] Bhasin, K. and Clark, P. (2016). *Amazon ha cambiato anche la robotica*. [online] Il Post. Available at: https://www.ilpost.it/2016/07/28/amazon-ha-cambiato-anche-la-robotica/ [Accessed 4 Jun. 2018].
[262] Polanyi, M. (1966). *The Tacit Dimension*. University of Chicago Press.
[263] Bhasin, K. and Clark, P. (2016). *Amazon ha cambiato anche la robotica*. [online] Il Post. Available at: https://www.ilpost.it/2016/07/28/amazon-ha-cambiato-anche-la-robotica/ [Accessed 4 Jun. 2018].
[264] Polanyi, M. (1966). *The Tacit Dimension*. University of Chicago Press.

or even driving – activities that used to be considered too difficult to automate successfully".[265] In the book, "*The second machine age*"[266], Erik Brynjolfsson and Andrew McAfee come to the same conclusions. As they claimed: "*our digital machines have escaped their narrow confines and started to demonstrate broad abilities in pattern recognition, complex communication, and other domains that used to be exclusively human. We have also recently seen great processes in natural language processing, machine learning (the ability of a computer to automatically refine its methods and improve its results as it gets more data), computer vision, simultaneous localization and mapping, and many of the other fundamental challenges of the discipline*".[267] The authors are convinced that the current state of progress of microprocessors are capable of doing things which a short time ago were considered only possible in the context of science-fiction serials. The point is that machines are not only able to beat humans at chess, but also to drive vehicles of any kind, translate texts from one language to another one, and perform multiple tasks[268]. For example, let's think of Google translate. At first, the machine translation service was able to interpret short word sequences without taking into account the context within which they were inserted. Nowadays, by using machine learning systems, every word is contextualized, and this make it possible to obtain a more precise translation[269]. IBM's Watson is a further example of the recent technological progress. Although it once seemed impossible for a computer to diagnose a disease, now they are used in the medical field to provide clinical support to doctors in lung cancer treatments. Furthermore, they are proving to be able to diagnose illness better than any doctor[270]. Erik Brynjolfsson and Andrew McAfee talk about a "*second machines age*"[271]: the 21st century technologies such as computers and artificial intelligence will change the way we carry out mental work as well as the steam engine revolutionized the way we carried out physical work. In other words, if the first machine age allowed the

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265 McKinsey (2017). *A future that works: automation, employment and productivity*. New York: McKinsey Global Institute.
266 Brynjolfsson, E. and McAfee, A. (2014). *The second machine age*. 1st ed. New York: W. W. Norton & Company.
267 Brynjolfsson, E. and McAfee, A. (2014). *The second machine age*. 1st ed. New York: W. W. Norton & Company, p. 52.
268 Brynjolfsson, E. and McAfee, A. (2014). *The second machine age*. 1st ed. New York: W. W. Norton & Company.
269 Longhitano, L. (2017). Google *Traduttore si avvicina alle capacità di un madrelingua*. [online] Wired. Available at: https://www.wired.it/internet/web/2017/04/20/google-traduttore-madrelingua/ [Accessed 4 Jun. 2018].
270 Brynjolfsson, E. and McAfee, A. (2014). *The second machine age*. 1st ed. New York: W. W. Norton & Company.
271 Brynjolfsson, E. and McAfee, A. (2014). *The second machine age*. 1st ed. New York: W. W. Norton & Company.

mankind to overcome the constraints of the physical world, the second age will lead people overcome their mental limitations. Furthermore, although first computers were able to perform predominantly routine activities, at present, in the face of recent digital developments, they are able to carry on increasingly complex tasks. In other words, "*historically, computerisation has been largely confined to manual and cognitive routine tasks involving explicit rule-based activities. Following recent technological advances, however, computerisation is now spreading to domains commonly defined as non-routine*"[272]. Therefore, recent technological advances are no longer confined to routine activities.

The task model developed by Autor et al (2003) provided useful information for understanding which types of jobs can be performed by computers. According to this model, computers can substitute workers in carrying out routine tasks. However, technological progress is complementary to workers who perform non-routine activities. Nowadays, technological advancements have made it possible for non-routine tasks to be automated as well. Therefore, the routine-biased technical change hypothesis is no longer valid, and it cannot be used to forecast the impact that Industry 4.0 technologies will have on the workforce composition.

Considering the recent technological developments, the two Oxford researchers Carl Benedikt Frey and Michael A. Osborne revisited the task model. For the purpose of their study, the authors tried to identify all activities that cannot be automated using artificial intelligence and, in general, the latest technologies of the Industry 4.0 due to the presence of "*problems engineers need to solve for specific occupations to be automated*"[273]. These measures have allowed to separate activities into susceptible and not susceptible to automation. While the task model states that computer can only perform routine work, Frey and Osborne's model provides that the human/machines substitution also applies to non-routine activities, to the exclusion of those that have engineering problems to computerisation. The latter include:

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[272] Frey, C. and Osborne, M. (2013). *The future of employment: How susceptible are jobs to computerisation?*. Technological Forecasting and Social Change, 114, p. 15.

[273] Frey, C. and Osborne, M. (2013). *The future of employment: How susceptible are jobs to computerisation?*. Technological Forecasting and Social Change, 114, p. 7.

- Perception and manipulation tasks: computer sensors are still unable to handle irregular objects and identify them in a blurred field of vision.
- Creative intelligence tasks: creativity is a complex function and it cannot be encoded and, therefore, automated.
- Social intelligence tasks: computers, at present, find it difficult to relate with humans. For example, "*the real-time recognition of natural human emotion remains a challenging problem, and the ability to respond intelligently to such inputs is even more difficult*".[274]

In short, tasks involving perception and manipulation, creative intelligence, and social tasks cannot be carried out by computer because recent technological advances have not managed to codify these activities yet. These so-called "engineering bottlenecks" were identified by relying upon data from a study conducted together with machine learning researchers (on 70 selected occupations) and a workshop held at the Oxford University Engineering Sciences Department. Then, nine objective variables describing these tasks were identified, by making use of the O*NET database. They are shown in the picture below (where the first three variables refer to social intelligence, the latter three variables refer to perception and manipulation tasks, and the remaining three to creative intelligence):

Variable	Probability of Computerisation		
	Low	Medium	High
Assisting and caring for others	48±20	41±17	34±10
Persuasion	48±7.1	35±9.8	32±7.8
Negotiation	44±7.6	33±9.3	30±8.9
Social perceptiveness	51±7.9	41±7.4	37±5.5
Fine arts	12±20	3.5±12	1.3±5.5
Originality	51±6.5	35±12	32±5.6
Manual dexterity	22±18	34±15	36±14
Finger dexterity	36±10	39±10	40±10
Cramped work space	19±15	37±26	31±20

[274] Frey, C. and Osborne, M. (2013). *The future of employment: How susceptible are jobs to computerisation?*. Technological Forecasting and Social Change, 114, p. 26.

Figure[275]

As automation costs decrease, employers are encouraged to replace worker with machines in carrying out many different activities susceptible to automation. This is because computers are more efficiently than humans in carrying out activities. First, "*little evidence is required to demonstrate that, in performing the task of laborious computation, networks of machines scale better than human labour. As such, computers can better manage the large calculations required in using large datasets*"[276]. Secondly, computers are not affected by human biases. Therefore, "*algorithms are free of irrational bias, and their vigilance need not be interrupted by rest breaks or lapses of concentration*".[277] Apparently, however, there are limits to the replacement capacity possessed by current technologies. Not all problems, in fact, can be embedded in a computer code and, therefore, automated. The model provides that "*the pace at which these bottlenecks can be overcome will determine the extent of computerisation in the twenty-first century*". [278] To examine the future direction of technological changes Carl Benedikt Frey and Michael A. Osborne used the O*NET (2010) data of the Bureau of Labour Statistics (BLS) department which provide a description of the skill requirements for each of the 702 occupations considered. Then, by comparing the variables relating to the engineering problems previously identified with those relating to occupations (through a probabilistic classification algorithm) they were able to assess how susceptible are jobs to digitalization. In particular, the authors identified three job categories: those at high-, medium-, and at low risk of automation. The purpose of their analysis was to identify which of the jobs existing in 2010 would have been at risk of automation. Vice versa, the authors did not seek to forecast the future employment change resulting from of introduction of the 21st technologies into production processes. First of all, technologies are at very early stage of development.

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[275] This estimation is based on data from machine-learning researches and a workshop held at the Oxford University Engineering Sciences Department. Frey, C. and Osborne, M. (2013). *The future of employment: How susceptible are jobs to computerisation?*. Technological Forecasting and Social Change, 114, p. 40.

[276] Frey, C. and Osborne, M. (2013). *The future of employment: How susceptible are jobs to computerisation?*. Technological Forecasting and Social Change, 114, p. 16.

[277] Frey, C. and Osborne, M. (2013). *The future of employment: How susceptible are jobs to computerisation?*. Technological Forecasting and Social Change, 114, p. 17

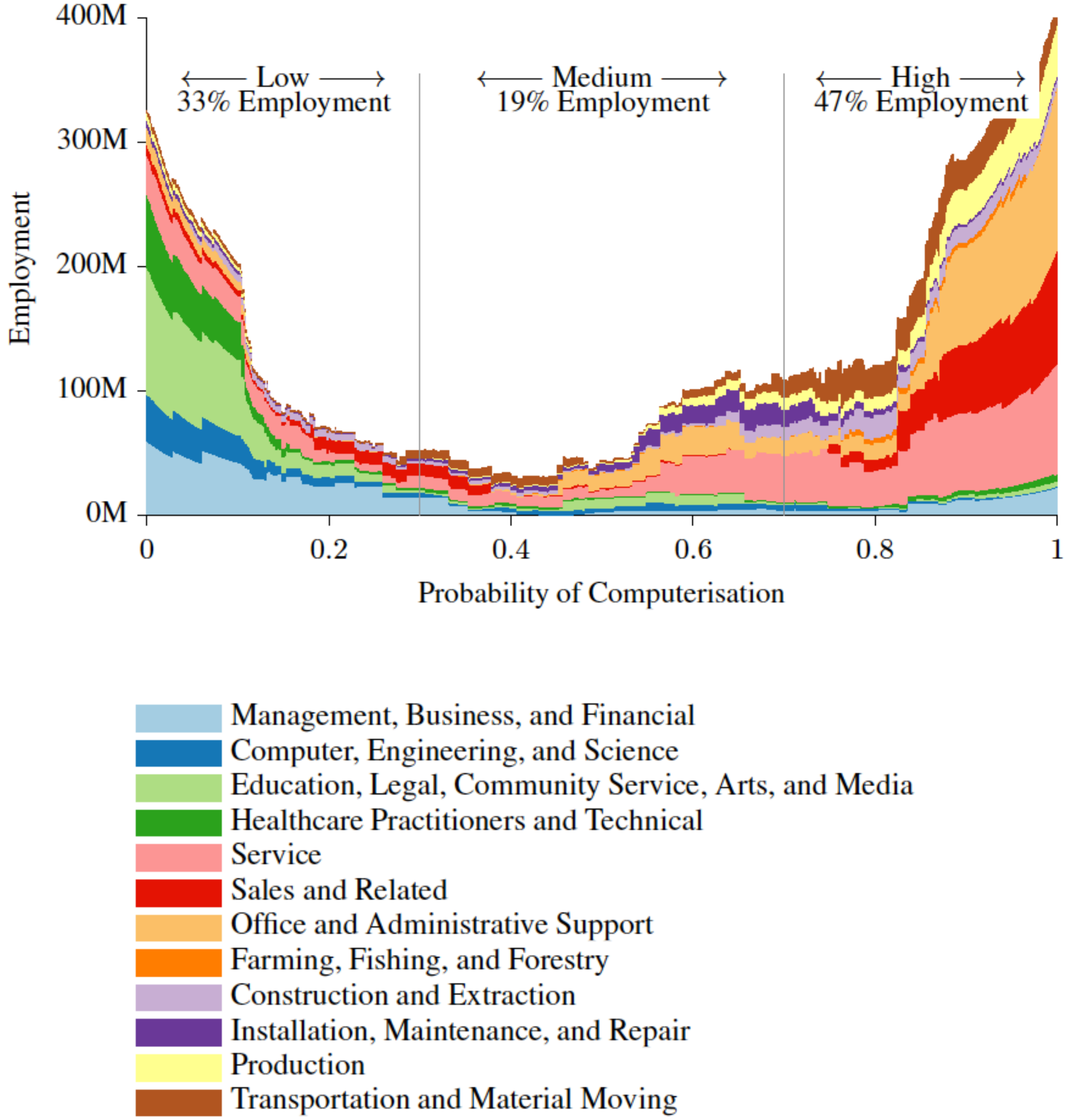
[278] Frey, C. and Osborne, M. (2013). *The future of employment: How susceptible are jobs to computerisation?*. Technological Forecasting and Social Change, 114, p. 23.

Therefore, historical data are not available for making such forecasts. Furthermore, it is not possible to determine what job opportunities will be created in the future. For example, "*nineteenth-century political economists lacked an ability to predict new job categories like the personal fashion consultants, cybersecurity experts, and online-reputation managers of the twenty-first century*". [279] Therefore, it would be reasonable to expect that new jobs will be created by technological progress in the near future, as has happened in the past.

In order to estimate the number of people employed in the high-, medium-, and low- risk occupations, the Labour Department's Standard Occupational Classification (SOC) data of the Bureau of Labour Statistics (BLS) were used. What Frey and Osborne's study reveal is that the next-generation machines will lead to the replacement of about 47% of the American workforce. Workers in the clerks, services and sales sectors will be the most heavily affected by technological unemployment (e.g. they are in the high-risk category). The education, health and management sectors are those less subject to the risk of automation owing to the presence of engineering problems which do not permit the codification of these jobs. It is only when persuasion, social and creative intelligence will be embedded in a computer code and, therefore, codified that these works will be completely automated. As a result of that workers employed in these sectors will be replaced by machinery. For example, transportation and logistics occupations belongs to the high-risk category since self-driving cars have already been developed and they will be soon put in the market. Furthermore, paralegals and legal assistants are in the high-risk of automation category as well. Existing technologies, in fact, enable to analyse millions of documents at the place of men by assisting lawyers in the pre-trial research. Conversely, robots cannot replace lawyers with machines since social and creative intelligence skills are required in the performance of this kind of occupation. These competences cannot be automated by considering the current state of technology. "*For the work of lawyers to be fully automated, engineering bottlenecks to creative and social intelligence will need to be overcome, implying that the computerisation of legal research will complement the work of lawyers in the medium term*".[280] Therefore,

[279] Mokyr, J., Vickers, C. and Ziebarth, N. (2015). *The History of Technological Anxiety and the Future of Economic Growth: Is This Time Different*?. Journal of Economic Perspectives, 29(3), p. 37.
[280] Frey, C. and Osborne, M. (2013). *The future of employment: How susceptible are jobs to computerisation?*. Technological Forecasting and Social Change, 114, p. 41.

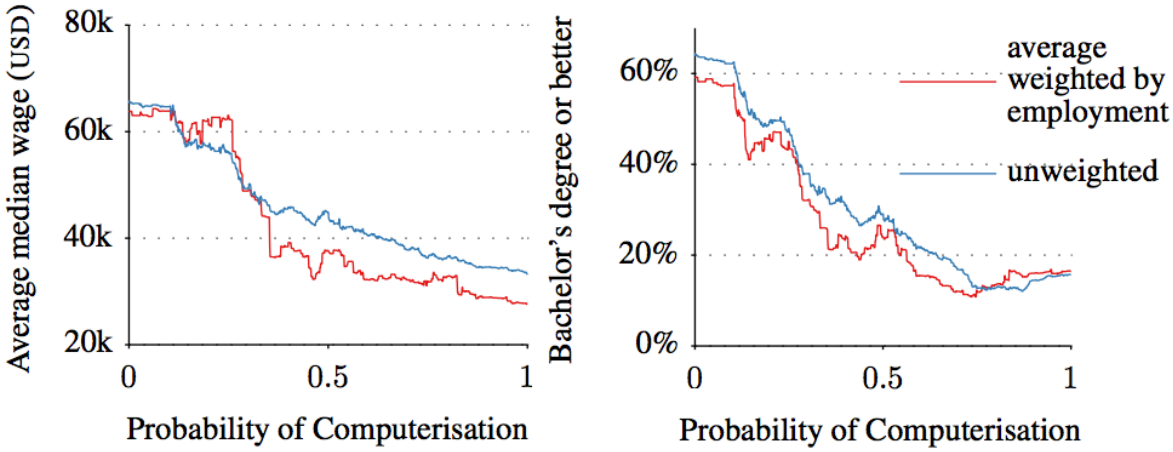
lawyers belong to the low-risk of automation category which accounts for the 33% of the total workforce. Management, business, education and media are other examples of occupations which are less exposed to the risk of automation. The remaining 19% of the workforce belongs to the medium-risk category of automation. The figure below illustrates this argument:



Figure[281]

On the y- axis is the change in employment, on the x-axis is the probability of computerisation. The latter "*can be seen as a timeline, where high probability occupations are likely to be substituted by computer capital relatively soon"*[282]. Therefore, initially, more and more occupations involving perception and manipulation tasks will be automated in the near future as technology becomes more advanced whereas occupations involving social and creative intelligence will not be automated until the engineering problems will be overcome. Finally, to complete the picture, Frey and Osborne analysed the impact of technology on wage and skill levels. In order to do that, they plotted "*the average median wage of occupations by their probability of computerisation (…) [They did] the same for skill level, measured by the fraction of workers having obtained a bachelor's degree*".[283] The study showed a negative correlation between the probability of automation and both employment and wage levels*:* where probability of computerization is high, wages and skill-levels are low and vice versa, as it is shown in the picture below[284].

[281] Frey, C. and Osborne, M. (2013). *The future of employment: How susceptible are jobs to computerisation?*. Technological Forecasting and Social Change, 114, p. 37.
[282] Frey, C. and Osborne, M. (2013). *The future of employment: How susceptible are jobs to computerisation?*. Technological Forecasting and Social Change, 114, p. 38.
[283] Frey, C. and Osborne, M. (2013). *The future of employment: How susceptible are jobs to computerisation?*. Technological Forecasting and Social Change, 114.
[284] Frey, C. and Osborne, M. (2013). The future of employment: *How susceptible are jobs to computerisation?*. Technological Forecasting and Social Change, 114, p. 42.

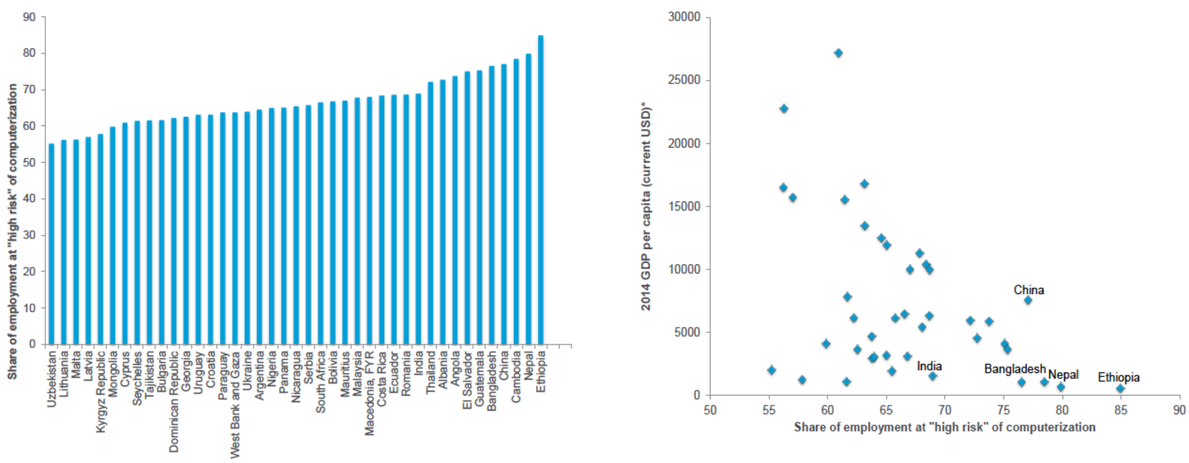


Figure[285]

This view is inconsistent with the current trend towards the polarization of labour market. Medium-skill occupations, in fact, fall into the medium-risk of automation category. Therefore, it is not expected that their labour demand will decrease in the foreseeable future. Or at least until engineering problems of computerisation linked to these tasks will be overcome. Conversely, employment will decrease for low-skilled workers who are the most at risk of automation. In fact, low-skilled workers mostly carry on jobs that belong to the high-risk category "*meaning that associated occupations are potentially automatable over some unspecified number of years, perhaps a decade or two*"[286]. High-skill and high-wage workers, instead, are the less subject to the risk of automation. All this could provide evidences supporting the skill-biased technical change hypothesis. According to it, technological progress increases the demand for high-skilled labour while, at the same time, it decreases the demand for unskilled labour. As a result of that, high-skilled workers' wages will increase. Conversely, the wages of less-skilled workers will decrease. Therefore, in the near future, we could be looking at a renewed upgrading pattern.

[285] Frey, C. and Osborne, M. (2013). *The future of employment: How susceptible are jobs to computerisation?*. Technological Forecasting and Social Change, 114, p. 41.
[286] Frey, C. and Osborne, M. (2013). *The future of employment: How susceptible are jobs to computerisation?*. Technological Forecasting and Social Change, 114, p. 38.

In 2016, the CITI GPS, by taking Frey and Osborne's model as its guideline, extended the analysis to the OECD countries in order to the evaluate how susceptible are jobs to automation at a global level. They used "*data from the World Bank to show that the risk of automation are actually higher in many other countries – for example, in the OECD the data shows on average 57% of jobs are susceptible to automation, this number rises to 69% in India and 77% in China*"[287].



Figure[288]

In the graph on the left: on the y-axis is the number of people employed in high-risk of automation occupations, on the x-axis is the countries. In the graph on the right: on the y-axis is the countries' GDP, on the x-axis is the number of people employed in the high-risk category. Automation is likely to come late in developing countries since human labour is more a cost-effective solution than automation. However, the more automation costs decrease the more capital will be employed in production processes, by substituting men with machines. The consequences brought about by automation will be tragic and implications will be deeper than developed countries (where the number of routine jobs is high). In fact, about two-thirds of occupations in developing countries bears a high-risk of automation

[287] Frey, C., Osborne, M. and Holmes, C. (2016). *TECHNOLOGY AT WORK v2.0 The Future Is Not What It Used to Be*. Citi GPS: Global Perspectives & Solutions.
[288] Frey, C., Osborne, M. and Holmes, C. (2016). *TECHNOLOGY AT WORK v2.0 The Future Is Not What It Used to Be*. Citi GPS: Global Perspectives & Solutions, p. 19.

compared to United State and Europe where the percentage of job exposed to automation is about 50-60%. For example, in Thailand this percentage is 72% compared to the 35% of United Kingdom.[289] A summary table showing the results of the research on the subject is provided below:

Country	Percentage of workers at risk of automation
United States	47%
United Kingdom	35%
Thailand	72%
Nigeria	65%
Argentina	65%
China	77%
South Africa	67%
India	69%
Ethiopia	85%
Finland	35%
Germany	59%

Figure[290]

Even if the 57% of the global workforce and the 47% of the American one (as estimated by C.B. Frey and M. Osborne) are at risk of automation, it does not necessarily mean that they will be effectively automated and, therefore, it is not possible to determine what the net effect on employment and wages will be. A number of factors should be considered in this respect. As noted above, Frey and Osborne's analysis does not allow to determine the way labour market will be changing since it is not possible to establish what job opportunities will be

[289] World Bank (2016). *Digital Dividends*. World Bank Development Report.

[290] Data taken from: Frey, C., Osborne, M. and Holmes, C. (2016). *TECHNOLOGY AT WORK v2.0 The Future Is Not What It Used to Be*. Citi GPS: Global Perspectives & Solutions. And: Arntz, M., Gregory, T. and Zierahn, U. (2016). *The Risk of Automation for Jobs in OECD Countries A COMPARATIVE ANALYSIS.* OECD Social, Employment and Migration Working Papers, (189).

created in the future. Therefore, any attempt to determine the future employment impact of technological progress will not be successful. In other words, at present, it is not possible to understand what the impact of Industry 4.0 will be on the future employment nor who the winners and losers will be. Technological progress is improving at an exponential rate, therefore, for this reason, the appearance of effects which are not yet fully recognized cannot be excluded. Furthermore, even if a new technology becomes available, it does not necessarily mean that it will be used in the production process. First of all, businesses must conduct a cost-benefit analysis in order to determine whether the new labour-saving technology will be more economical and efficient to use than human labour. This assessment is also dependent upon labour market dynamics. In fact, if workers' supply increases, while demand remains constant, wages will fall. Then, human labour could become cheaper than machines and, therefore, businesses may find it profitable to not resort to automation. For example, the McKinsey Global Institute estimated that "*just over $1 trillion in wages could be economically automated with a technology cost of $20 per hour, and $2 trillion could be captured with an automation cost of $10 per hour*"[291]. It is no less true, however, that costs of new technologies are progressively diminishing[292] (even if to this one should add the installation and programming costs which can be quite high: it is estimated that they represent the 35-45% of the total automation expense).[293] According to the Boston Consulting Group (BCG) the cost of robots will decrease from $133.000 to $103.000 in twenty-year's time Another factor that has to be considered concerns the benefits produced by the use of the new technology in production process. Will it increase output level or reduce errors? Will it bring more flexibility and increase product quality? Is human labour better? The lack of skilled labour needed to operate the machines may be another obstacle to the dissemination of technologies. All these aspects should be considered when assessing whether to substitute workers with machines. Furthermore, a new technology can be effectively deployed only if the regulatory framework allows its use. For example, countries' legislation (California and

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[291] Manyika, J., Chui, M., Bughin, J., Dobbs, R., Bisson, P. and Marrs, A. (2013). *Disruptive technologies: Advances that will transform life, business, and the global economy*. McKinsey Global Institute Report, p. 50.

[292] Frey, C., Osborne, M. and Holmes, C. (2016). *TECHNOLOGY AT WORK v2.0 The Future Is Not What It Used to Be*. Citi GPS: Global Perspectives & Solutions, p. 90.

[293] Frey, C., Osborne, M. and Holmes, C. (2016). *TECHNOLOGY AT WORK v2.0 The Future Is Not What It Used to Be*. Citi GPS: Global Perspectives & Solutions, p. 90.

Nevada in particular) is changing to encourage drive-less cars' entry in road traffic. However, until legal obstacles will not be overcome, the effective deployment of technologies will delay. Furthermore, social acceptance is another obstacle to automation deployment. "*While a robot in theory could carry out some functions of a nurse or a home-care help, the human beings on the receiving end of their care may balk at the idea*".[294] Through the course of history, people had always refused and rejected new technologies, and this led to a delay in their application.

Nowadays, technologies enable to automate only specific parts of activities consisting of multiple interrelated elementary activities. Despite significant progress in the field of artificial intelligence and big data, technologies are still in an embryonic stage. An example of this is the recent car accident which occurred in Arizona involving a bystander and the Uber's self-driving car. Uber was recently using Google's self-driving car as part of its taxy-service. The car, which was driving at a speed of 65 miles per hour, was not able to identify the pedestrian who was crossing the road because of the absence of an illuminating surface. A car driven by a safer driver, however, would have managed to prevent the accident or minimise the damage. This provides supporting evidence that there are few jobs that can be completely automated. Machines are still unable to completely substitute human activity. As stated by McKinsey: "*Less than 5 percent of all occupations can be automated entirely using demonstrated technologies*"[295].

Even if, at present, it is not possible to forecast the future employment effects arising from technological developments, it is important, however, that all countries' stakeholders work together to better understand labour market dynamics and adjust their systems promptly.

In the final analysis, a summary table showing the results of the major research on the subject is provided below:

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[294] Manyika, J., Chui, M., Bughin, J., Dobbs, R., Bisson, P. and Marrs, A. (2013). *Disruptive technologies: Advances that will transform life, business, and the global economy*. McKinsey Global Institute Report, p. 52.

[295] Frey, C. and Osborne, M. (2013). *The future of employment: How susceptible are jobs to computerisation?*. Technological Forecasting and Social Change, 114.

Research	Frey and Osborne	Citibank with Frey and Osborne	OECD	World Economic Forum	McKinsey Global Institute
Date	September 2013	January 2016	June 2016	January 2016	January 2017
Unit of analysis	Jobs/occupations	Jobs/occupations	Tasks	Not applicable	Work activities
Scope	US labour market	50+ countries and regions	21 OECD countries	15 major developed and emerging economies	46 countries
Approach summary	Analysis of 702 occupations (70 hand-labeled working with ML researchers, followed by a tailored Gaussian process classifier to estimate others and confirm hand-labels) to approximate the impact of future computerizatio	Extension of Frey-Osborne (2013), using World Bank data, to estimate impact of automation globally.	Estimates of automatability of tasks were developed based on matching of the automatability indicators by Frey-Osborne and the PIAAC data occupational codes, followed by	Analysis of large-scale survey of major global employees, including 100 largest global employers in each of WEF main industry sector, to estimate the expected level of changes in job families between 2015-2020	Disaggregation of occupations into 2.000 constituent activities and rating each against human performance in 18 capabilities. Further analysis of time spent on each activity and

	n on the US labour market		a two-step, tailored regression analysis	and extrapolate number of jobs gained/lost	hourly wage levels. Scenarios for development and adoption of automation technologies
Key relevant findings	• About 47% of total US occupations are at high risk of automation perhaps over the next decade or two • Wages and educational attainment show a strong negative relationship with probability of	• Building on Frey and Osborne's original work, data from the World Bank suggests the risks are higher in many other countries; in the OECD, on average 57% of	• On average, 9% of jobs across the 21 OECD countries are automatable • There are notable differences across OECD countries when it comes to	• Automation and technological advancements could lead to a net employment impact of more than 5.1 million jobs lost to disruptive labour market changes between	• Almost half of work activities globally have the potential to be automated using current technology. <5% of occupations can be automated entirely;

	computerization	jobs are susceptible to automation. This number rises to 69% in India and 77% in China	automation (e.g., the share of automatable jobs is 6% in Korea vs. 12% in Austria)	2015 - 20 with a total loss of 7.1 million jobs- two-thirds of which are concentrated in the office and administrative job family – and a total gain of 2 million jobs in several smaller job families	about 60% have at least 30% of automatable activities • Technically automatable activities touch 1.1 billion workers and $15.8 trillion in wages. China, India and United States constitut

					e over half

Figure[296]

[296] Manyika, J., Chui, M., Bughin, J., Dobbs, R., Bisson, P. and Marrs, A. (2013). *Disruptive technologies: Advances that will transform life, business, and the global economy*. McKinsey Global Institute Report

Conclusions

The subject matter of this thesis concerns the profound changes brought about by technological progress in the labour market and in the global economic structure. There are many different views on the issue. On one hand, the techno-optimists believe in the goodness of technological progress by only looking at the positive effects it generates. On the other, concerns regarding the harmful consequences of the introduction of new machines into production processes have been expressed by the techno-pessimists. A more realistic approach should, instead, gain an in-depth understanding of the phenomenon to appreciate the positive aspects arising from the deployment of new technologies while at the same time forecasting potential risks. The previous industrial revolutions "assaulted" routine activities, either manual or cognitive, because these functions can be easily codified and, therefore, automated. The news coming down from the Industry 4.0 is that many of the activities classified as "non-routine" can in practice be automated and executed by machines and robots. However, to date, not all jobs are at risk of being automated, but only specific activities. Even if the technological frontier is moving forward, we are still very far from replacing human labour with machines in jobs that require flexibility, discretion and that, more broadly, are not suitable for being encoded. From that point of view, one has to question what the impact of technological progress will be in terms of job losses (quantitative effect) and what kind of work people will do (qualitative effect). There is no convergence of views among economists with regard to the impact of the fourth industrial revolution on employment levels. If it is easy to estimate how many jobs will be lost, it is certainly harder to forecast how many of them will be created. Conversely, all studies agree that major changes will take place in the labour market. Workers will need to upgrade their skills to ensure they do not lose the "race against the machines". The fourth industrial revolution will bring benefits as well as new challenges. The new wave of innovation could create major distortions, by giving skilled workers an edge and disadvantaging the less skilled ones. Labour market must adapt to the changing business world accordingly and, therefore, the national education systems need to offer adequate training and re-training to the future workforce. Obviously, it is crucial that the government does not underestimate the importance and potential implications of technological developments. The government plan will have to provide for incentives for additional training, besides tax concessions. In the near future, workers with the proper instruction and soft-skills are less likely to experience technological unemployment. In conclusion, because skilled workers are substantially less susceptible to automation, the best hope for economies alike is to upskill their workforce.

REFERENCES

Acemoglu, D. (2002). *Technical Change, Inequality, and the Labor Market*. Journal of Economic Literature, 40(1), p. 20.

Acemoglu, D. and Autor, D. (2011). *Skill, Tasks, and Technologies: Implications for Employment and Earnings*. In: O. Ashenfelter and D. Card, ed., Handbook of Labor Economics. Elsevier, pp 1044-1166.

Acemoglu, D. and Restrepo, P. (2017). *Robots and Jobs: Evidence from US Labor Markets*. SSRN Electronic Journal.

Agostini, S. (2015). *Cina, robot al posto dei lavoratori per rispondere all'aumento dei salari - Il Fatto Quotidiano*. [online] Il Fatto Quotidiano. Available at: https://www.ilfattoquotidiano.it/2015/09/04/cina-robot-al-posto-dei-lavoratori-per-rispondere-allaumento-dei-salari/2006855/ [Accessed 2 Jun. 2018].

Arntz, M., Gregory, T. and Zierahn, U. (2016). *The Risk of Automation for Jobs in OECD Countries A COMPARATIVE ANALYSIS*. OECD Social, Employment and Migration Working Papers, (189).

Atkeson, A. and Kehoe, P. (2001). *The transition to a new economy after the second industrial revolution*. NBER Working Paper series.

Autor, D. and Dorn, D. (2013). *The Growth of Low-Skill Service Jobs and the Polarization of the US Labor Market*. American Economic Review, 103(5), pp.1553-1597.

Autor, D., Dorn, D. and Hanson, G. (2015*). Untangling Trade and Technology: Evidence from Local Labour Markets*. The Economic Journal, 125(584), pp.621-646.

Autor, D., Levy, F. and Murnane, R. (2003). *Skill demand, Inequality, and Computerization: Connecting the Dots*. In: D. Ginther, ed., TECHNOLOGY, GROWTH, AND THE LABOR MARKET. Kluwer Academic Publishers, pp. 107-129.

Autor, D., Levy, F. and Murnane, R. (2003). *The Skill Content of Recent Technological Change: An Empirical Exploration*. The Quarterly Journal of Economics, 118(4), pp.1279-1333.

Autor, D., Katz, L. and Krueger, A. (1998). *Computing Inequality: Have Computers Changed the Labor Market?*. The Quarterly Journal of Economics, 113(4), pp.1169-1213.

Bank of England (2016). *A millennium of macroeconomic data*. [online]

Bankofengland.co.uk. Available at: https://www.bankofengland.co.uk/statistics/research-datasets [Accessed 26 May 2018].

Bhasin, K. and Clark, P. (2016). *Amazon ha cambiato anche la robotica*. [online] Il Post. Available at: https://www.ilpost.it/2016/07/28/amazon-ha-cambiato-anche-la-robotica/ [Accessed 4 Jun. 2018].

Beckworth, D. (2011). *The Great Stagnation and Total Factor Productivity*. [online] Macromarketmusings.blogspot.it. Available at: http://macromarketmusings.blogspot.it/2011/02/great-stagnation-and-total-factor.html [Accessed 4 May 2018].

Beltrametti, L., Guarnacci, N., Intini, N. and La Forgia, C. (2017). *La fabbrica connessa*. La manifattura italiana (attra)verso Industria 4.0. Milano: Guerini e Associati.

Berman, E., Bound, J. and Griliches, Z. (1994). *Changes in the Demand for Skilled Labor within U. S. Manufacturing: Evidence from the Annual Survey of Manufactures*. The Quarterly Journal of Economics, 109(2), pp.367-397.

Bernstein, A. and Raman, A. (2015). *The Great Decoupling: An Interview with Erik Brynjolfsson and Andrew McAfee*. Harvard Business Review. [online] Available at: https://hbr.org/2015/06/the-great-decoupling [Accessed 3 May 2018].

Blanchard, O., Amighini, A. and Giavazzi, F. (2011). *Macroeconomia: una prospettiva europea*. Bologna: Il mulino.

Braverman, H. (1998). *Labor and Monopoly Capital The Degradation of Work in the Twentieth Century*. New York: Monthly Review Press.

Bresnahan, T. and Trajtenberg, M. (1995). *General purpose technologies 'Engines of growth'*?. Journal of Econometrics, 65(1), pp.83-108.

Brynjolfsson, E. (1993). *The productivity paradox of IT: review and assessment*. Communications of the ACM.

Brynjolfsson, E. and Hitt, L. (2003). *Computing Productivity: Firm-Level Evidence*. SSRN Electronic Journal.

Brynjolfsson, E. and McAfee, A. (2011). *Race against the machine: how the digital revolution is accelerating innovation, driving productivity, and irreversibly transforming employment and the economy*. Lexington, Massachusetts: Digital Frontier Press.

Brynjolfsson, E. and McAfee, A. (2014). *The second machine age*. 1st ed. New York: W. W. Norton & Company.

Cipriani, A., Gramolati, A. and Mari, G. (2018*). Il lavoro 4.0: La Quarta Rivoluzione industriale e le trasformazioni delle attività lavorative*. Firenze: Firenze University press.

Clark, G. (2012). Review: *A Review Essay on "The Enlightened Economy: An Economic History of Britain 1700–1850" by Joel Mokyr*. Journal of Economic Literature, 50(1), pp.85-95.

Clark, G. (2001). *The Secret History of the Industrial Revolution. Department of Economics Working Papers*, pp.1-72.

Cowen, T. (2011). *The Great Stagnation*. Penguin Group US.

Cyert, R. and Mowery, D.C. (1987). *Technology and Employment: Innovation and Growth in the U.S. Economy*. Washington, D.C.: National Academy Press.

David, P. (1990). *The Dynamo and the Computer: An Historical Perspective on the Modern Productivity Paradox*. The American Economic Review, 80(2), pp.355-361.

Deloitte (2015). *Technology and people: The great job-creating machine*. Deloitte LLP, p. 5.

De Simone, E. (2012). *Storia economica: dalla rivoluzione industriale alla rivoluzione informatica*. 4th ed. Milano: Franco Angeli.

Desjonqueres, T., Machin, S. and Van Reenen, J. (1999). *Another Nail in the Coffin? Or Can the Trade Based Explanation of Changing SkillStructures Be Resurrected*?. The Scandinavian Journal of Economics, 101(4), pp.533-554.

DiNardo, J., Fortin, N. and Lemieux, T. (1995). *Labour Market Institutions and the Distribution of Wages, 1973-1992: a semiparametric approach*. NBER Working Papers.

DiNardo, J. and Pischke, J. (1996). THE RETURNS TO COMPUTER USE REVISITED: HAVE PENCILS CHANGED THE WAGE STRUCTURE TOO?. NBER WORKING PAPER SERIES.

Eurofound (2014). *Drivers of recent job polarisation and upgrading in Europe*. European Jobs Monitor 2014.

European Commission (2017). *Germany: Industrie 4.0*. Digital Transformation Monitor.

European Commission (2017). *Italy: "Industria 4.0"*. Digital Transformation Monitor.

Firpo, S., Fortin, N. and Lemieux, T. (2011). *Occupational Tasks and Changes in the Wage Structure*. Forschungsinstitut zur Zukunft der Arbeit Institute for the Study of Labor.

Fleck, S., Glaser, J. and Sprague, S. (2011). *The compensation-productivity gap: a visual essay*. Monthly Labor Review. [online] Available at: https://www.bls.gov/opub/mlr/2011/01/art3full.pdf [Accessed 19 May 2018].

Floud, R., Humphries, J. and Johnson, P. (2014). *The Cambridge economic history of modern Britain*. Cambridge: Cambridge University Press.

Foresti, G., Guelpa, F. and Trenti, S. (2007). *La terziarizzazione dell'economia europea: è vera deindustrializzazione?*. Intesa SanPaolo collana ricerche.

Freeman, C. and Louçã, F. (2001). *As times goes by: from the industrial revolutions to the information revolution*. New York: Oxford University Press.

Frey, C., Osborne, M. and Holmes, C. (2016). *TECHNOLOGY AT WORK v2.0 The Future Is Not What It Used to Be*. Citi GPS: Global Perspectives & Solutions.

Frey, C. and Osborne, M. (2013). *The future of employment: How susceptible are jobs to computerisation?*. Technological Forecasting and Social Change, 114, pp 13.

Gavetti, G.M., Henderson, R. and Giorgi, S. (2005). *Kodak and the Digital Revolution*. Harvard Business School.

Greenwood, J., Yorukoglu, M. (1997). 1974. *Carnegie-Rochester conference series on public policy*, 46:North–Holland, p.87

Goldin, C., and Katz, L.F. (1998). "*The Origins of Technology-Skill Complementarity*". The Quarterly Journal of Economics 113 (3).

Goldin, C. and Katz, L.F. (2009). *The race between education and technology*. Cambridge, Mass.: Belknap.

Goos, M., Manning, A. and Salomons, A. (2011). *Explaining Job Polarization: The Roles of Technology, Offshoring and Institutions*. SSRN Electronic Journal.

Goos, M., Manning, A. and Salomons, A. (2009). *Job Polarization in Europe*. American Economic Review, 99(2), pp.58-63.

Gordon, R. (2012). *Is U.S. Economic growth over? Faltering innovation confronts the six headwinds*. NBER working papers.

Hicks, J. (1957). *The theory of wages*. Gloucester, Mass.: Peter Smith.

Howell, D. and Wolff, E. (1992). *Technical change and the demand for skills by US industries*. Cambridge Journal of Economics, 16(2), pp.127-146.

Jorgenson, D., Ho, M. and Stiroh, K. (2004*). Will the U.S. Productivity Resurgence Continue*?. Federal Reserve Bank of New York, 10(13).

Jung, J. and Mercenier, J. (2014). *Routinization-biased technical change and globalization: understanding labor market polarization*. Economic Inquiry, 52(4), pp.1446-1465.

Kagermann, H., Anderl, R., Gausemeier, J., Schuh, G. and Wahlster, W. (2016). *Industrie 4.0 in a Global Context*. Acatec Study.

Katz, L. and Margo, R. (2013). *TECHNICAL CHANGE AND THE RELATIVE DEMAND FOR SKILLED LABOR: THE UNITED STATES IN HISTORICAL PERSPECTIVE*. NBER WORKING PAPER SERIES.

Keynes, J. (1931). *Essays in persuasion*. London: Macmillan, pp.321-334.

Korinek, A. and Stiglitz, J.E. (2017). *Artificial intelligence and its implications for income distribution and unemployment*. NBER Working Paper Series.

KPMG (2017). *Industria 4.0 per un'Impresa globale: la dimensione del fenomeno, le implicazioni per il Paese, le policy*. Comitato Leonardo – Italian Quality Committee, pp.15-27.

Krugman, P., Obstfeld, M. and Melitz, M. (2011). *International Economics theory and policy*. 9th ed. Pearson.

Levy, F. and Murnane, R. (2004). *The New Division of Labor: How Computers are Creating the Next Job Market*. Princeton: Princeton University Press.

Longhitano, L. (2017). *Google Traduttore si avvicina alle capacità di un madrelingua*. [online] Wired. Available at: https://www.wired.it/internet/web/2017/04/20/google-traduttore-madrelingua/ [Accessed 4 Jun. 2018].

Lorenz, M., Rüßmann, M., Strack, R., Lueth, K. and Bolle, M. (2015). *Man and Machine in Industry 4.0 How Will Technology Transform the Industrial Workforce Through 2025?.* Boston Consulting Group.

Machin, S. and Van Reenen, J. (1998). *Technology and Changes in Skill Structure: Evidence from Seven OECD Countries*. The Quarterly Journal of Economics, 113(4), pp.1215-1244.

Magazzino, C. and Romagnoli, G.C. (2014). *Legge di stabilità e finanza pubblica in Italia*. FrancoAngeli.

Magone, A. and Mazali, T. (2016). *Industria 4.0: Uomini e macchine nella fabbrica digitale*. Milano: Guerini.

Malik, O. (2015). *In Silicon Valley Now, It's Almost Always Winner Takes All*. The Newyorker. [online] Available at: https://www.newyorker.com/tech/elements/in-silicon-valley-now-its-almost-always-winner-takes-all [Accessed 19 May 2018].

Manyika, J., Chui, M., Bughin, J., Dobbs, R., Bisson, P. and Marrs, A. (2013). *Disruptive technologies: Advances that will transform life, business, and the global economy*. McKinsey Global Institute Report.

Marengo, L. (2018). *Concentrazioni industriali e rendite di posizione, ecco i frutti avvelenati dell'economia digitale*. [online] Open.luiss.it. Available at: http://open.luiss.it/2018/01/24/concentrazioni-industriali-e-rendite-di-posizione-ecco-i-frutti-avvelenati-delleconomia-digitale/ [Accessed 20 May 2018].

Marx, K. (1982). *Economic and philosophic manuscripts of 1844*. Translated by Martin Milligan. Moscow: Progress Publishers.

Marx, K. and Eugenio, S. (1968). *Il capitale*. Roma: Newton Compton Editori.
Ministry of Economic Development (2017). *Incentives to investors: Italy's Industria 4.0 plan*. [online] Investorvisa.mise.gov.it. Available at: https://investorvisa.mise.gov.it/index.php/en/home-en/incentives-to-investors-italy-s-industria-4-0-plan [Accessed 22 May 2018].

Mokyr, J., Vickers, C. and Ziebarth, N. (2015). *The History of Technological Anxiety and the Future of Economic Growth: Is This Time Different*?. Journal of Economic Perspectives, 29(3), pp.31-50.

Moore, G. (1998). *Cramming More Components Onto Integrated Circuits*. Proceedings of the IEEE, 86(1), pp.82-85.

Munarriz, R. (2008). *Blockbuster CEO Has Answers*. [online] The Motley Fool. Available at: https://www.fool.com/investing/general/2008/12/10/blockbuster-ceo-has-answers.aspx [Accessed 12 May 2018].
National Research Council (1983). *The Long-Term Impact of Technology on Employment and Unemployment*. Washington, DC: The National Academies Press, p.3.

Naticchioni, P., Ragusa, G. and Massari, R. (2014). *Unconditional and Conditional Wage Polarization in Europe*. Forschungsinstitut zur Zukunft der Arbeit Institute for the Study of Labor.

Ohno, T. (1978). *Toyota Production System: Beyond Large-Scale Production*. Portland, Oregon: Productivity Press.

Oliner, S. and Sichel, D. (2000). *The Resurgence of Growth in the Late 1990s: Is Information Technology the Story?*. SSRN Electronic Journal.

Pianta, M. (2006). *Innovation and employment*. In: J. Fagerberg, D. Mowery and R. Nelson, ed., The Oxford Handbook of Innovation. [online] Oxford University Press. Available at: https://works.bepress.com/mario_pianta/31/ [Accessed 3 May 2018].

Polanyi, M. (1966). *The Tacit Dimension*. University of Chicago Press.

Reati, A. (2001). *Total factor productivity – A misleading concept*. BNL Quarterly Review.
Ricardo, D. (1817). *On the principles of political economy and taxation*. London: John Murray.

Rifkin, J. (2012*). The Third Industrial Revolution: How the Internet, Green Electricity, and 3-D Printing are Ushering in a Sustainable Era of Distributed Capitalism*. The World Financial Review, pp.8-12.

Rifkin, J. (1995). *The End of Work: The Decline of the Global Labor Force and the Dawn of the Post-Market Era*. Putnam Publishing Group.

Roland Berger (2014). *INDUSTRY 4.0 The new industrial revolution How Europe will succeed*. Roland Berger Strategy Consultants.

Roland Berger (2016). *The Industry 4.0 transition quantified: How the fourth industrial revolution is reshuffling the economic, social and industrial mode*. Roland Berger GMBH.

Rosen, S. (1981). *The Economics of Superstars*. The American Economic Review, 71(5), pp.845-858.

Schumpeter, J. A. (1934), *Theory of Economic Development*. Cambridge, Mass.: Harvard University Press.

Schwab, K. (2016). *La quarta rivoluzione industriale*. Milano: FrancoAngeli.

Smith, A. and Cannan, E. (1994). *An inquiry into the nature and causes of the wealth of nations*. New York: Modern Library.

Solow, R.M. (1987). *We'd Better Watch Out*. New York Times Book Review.

Solow, R.M. (2018). *Technical Change and the Aggregate Production Function*. The Review of Economics and Statistics, 39(3), pp.312-320.

Sprague, S. (2017). *Below trend: the U.S. productivity slowdown since the Great Recession*. Bureau of Labor Statistics, [online] 6(2). Available at: https://www.bls.gov/opub/btn/volume-6/below-trend-the-us-productivity-slowdown-since-the-great-recession.htm [Accessed 7 May 2018].

Stiroh, K. (2001). *Information Technology and the U.S. Productivity Revival: What do the Industry Data Say?*. SSRN Electronic Journal.

Taisch, M. and De Carolis, A. (2016). *La Quarta Rivoluzione Industriale nel mondo*. [online] Industria Italiana: analisi & news su economia reale, innovazioni, digital transformation. Available at: https://www.industriaitaliana.it/la-quarta-rivoluzione-industriale-nel-mondo/ [Accessed 22 May 2018].

Taylor, F.W. (1911). *The Principles of Scientific Management.* Cosimo Classics.

Violante, G. (2008). *Skill-Biased Technical Change*. In: S. Durlauf and L. Blume, ed., The New Palgrave Dictionary of Economics, 2nd ed. Palgrave Macmillan.

Vivarelli, M. (1995), *The Economics of Technology and Employment: Theory and* Empirical Evidence. Aldershot: Elgar.

Wood, A. (1998). *Globalisation and the Rise in Labour Market Inequalities*. The Economic Journal, 108(450), pp.1463-1482.

World Bank (2016). *Digital Dividends*. World Bank Development Report.

World Economic Forum (2016). *The Future of Jobs Employment, Skills and Workforce Strategy for the Fourth Industrial Revolution*. Global Challenge Insight Report.

DEPARTMENT OF BUSINESS AND MANAGEMENT

Master Thesis in International Economics and Industrial Dynamics

THE ICTs REVOLUTION: ROUTINE-BIASED TECHNICAL CHANGE AND SOCIAL INEQUALITY

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ABSTRACT

Chapter 1: From the steam engine to the "second machines age"

The history of mankind has been affected by millennia of technological progress: starting with the advent of the steam engine and the electric motor, up to the most recent diffusion of personal computers (PCs) and the digitization. Each of these innovations has fundamentally changed not only industries but also the society as a whole, by transforming the labour market and affecting economic welfare and the distribution of income. The debate on the employment effect of technological progress dates back to the Luddites' revolt when some British weavers attacked the mechanical looms introduced during the first industrial revolution because of the fear that these industrial engines could stole their jobs. In the long run, however, the employment impact of technologies has been positive: more jobs were created than lost. Luddites' fears proved to be baseless and, for this reason, it is common to hear about the "Luddite fallacy". The steam engine is usually considered to be the symbol of the first industrial revolution. However, the importance that is placed on the steam engine has to be reduced since productivity gains deriving from its exploitation emerged only at a later stage. The first phase of the revolution was characterized indeed by other important innovations such as the human-powered spinning-jenny and the water-frame which were applied mainly to the textile sector. The second industrial revolution is considered to be more important compared to the first one since the technological renewal invested all sectors of the economy. There is an important difference between the technologies of the first and those of the second industrial revolution. The 19th century technologies were "de-skilling" in that skilled craftsmen were replaced by machines in carrying out their activities, which, in turn, were operated by unskilled workers. Conversely, the hallmark of second industrial revolution was the establishing of a complementary relationship between technology and human labour, that has been maintained to the present day. Where this difference come from? There are two theories about this. According to one line of thought, technology is an exogenous factor. The XIX century technologies were deskilling because the "*technological frontier (…) only* *enabled the invention of skill-replacing techniques*"[297]. Conversely, the technological progress of the XX century resulted in the creation of devices requiring skilled labour. An alternative theory, which was supported also by Daron Acemoglu, holds that technology is an endogenous factor and it builds upon incentives. This means that technological progress reflects the availability of skills. Therefore, "*the emergence of the most skill- replacing technologies of the past two-hundred years, the factory system, coincided with a large change in relative supplies. This time, there was a large migration of unskilled workers (...) [which] created profit opportunities for firms to exploit by introducing technologies that could be used with unskilled workers*"[298]. Conversely, the large supply of skilled workforce of the XX century made it profitable to develop skill-intensive technologies. Therefore, not only technological progress affects the demand for skill, but also labour supply, either skilled or unskilled, may have exerted some influence over technological developments.

Chapter 2: The ICTs revolution and labour market dynamics

Starting from the second half of the twentieth century, a noticeable acceleration of technological progress occurred. This brought numerous questions on the consequences that the spread of Information and Communications Technologies (ICTs) will have on the economy and on the functioning of the labour market. While the first machine age allowed the mankind to overcome the constraints of the physical world, the "*second machines age*"[299] changed the way people carry out mental work since they allowed for automating cognitive tasks too. Before considering the employment impact of technological progress, Solow's exogenous growth theory should be mentioned. According to the author, capital accumulation and technological progress are the only two factors that may lead to an increase of the output. If capital accumulation cannot drive economic growth forever, growth

[297]Acemoglu, D. (2002). *Technical Change, Inequality, and the Labor Market*. Journal of Economic Literature, 40(1), p. 11.
[298] Acemoglu, D. (2002). *Technical Change, Inequality, and the Labor Market*. Journal of Economic Literature, 40(1), p. 7.
[299] Bryniolfsson, E. and McAfee, A. (2014). *The second machine age*. 1st ed. New York: W. W. Norton & Company.

necessarily has to come from technological improvements. In other words, technological progress is a pre-requisite for achieving sustained output growth. Furthermore, Solow's economic growth model assumes that technological progress is an "Hicks-neutral" factor, meaning that it influences inputs in the same way, not by modifying their marginal rate of substitution. Technological progress increases the marginal productivity of all inputs and, therefore, it can be defined as total factor productivity augmenting. The total factor productivity (TFP), also known as multi-factor productivity, is a measure of economic efficiency and it is often considered the primary contributor to the economic growth rate. However, it does not seem to be used very often in practice owing to the presence of a number of weaknesses. First of all, it derives from a neoclassical production function which itself builds upon a series of unrealistic assumptions that are not always reflected in reality. For example, the hypothesis of the perfect competition model is hard to find in today's economic reality. Furthermore, it is not able to represent the key characteristics of the recent technological change. Because of the total factor productivity (TFP) index's flaws, other indices are used to measure economic performance. Among these, labour productivity is the one which is most frequently used and is the most well-known. Both labour and total factor productivity increased significantly until the 1970s. However, after this period, a significant downwards trend in terms of productivity took place. Indices, in fact, documented a poor performance of productivity growth. The widespread diffusion of information and communications technologies (ICTs) should have led to an improvement of the various productivity indices. However, statistics showed a disappointing productivity trend compared to what occurred in the past. This phenomenon has been called *"productivity paradox"*[300]. Many authors blamed information and communications technologies (ICTs) for the productivity slowdown. According to them, the technological improvements of the third industrial revolution could not be considered to be as important as those of ages past. Nevertheless, empirical data denied this pessimistic thesis. In fact, since the 1990s, productivity increased significantly. Several reasons have been advanced to explain why productivity recovery happened twenty years after the introduction of computers in

[300] Solow, R.M. (1987). *We'd Better Watch Out*. New York Times Book Review, p. 36.

production processes. Erik Brynjolfsson identified four possible explanations of the productivity paradox: the lag hypothesis, poor management performance, redistribution of profits and measurement errors. Each of these hypotheses is examined in detail in the chapter. If technological progress exerts a positive impact on economic growth, the effects that it might have on labour market are less clear cut and indeed subject of some dispute. Economists have always wondered about the effects of technology in terms of employment. Some argue that the introduction of technological innovations in production processes has a negative effect since it involves the substitution of human labour by machines. Others, however, consider the substitution effect a short-term phenomenon. Over time, the market mechanisms will lead to the development of new productive sectors and, therefore, new job opportunities could be created. Actually, what was claimed by the techno-pessimists has not occurred since, from the beginning of the industrial era, there has been a simultaneous increase in productivity and employment. Despite the numerous and profound changes brought about by technology, the total number of jobs has always increased. The production processes, through the adoption of new technologies, have become more efficient and, therefore, they have enabled sales prices reductions. As a result of that, the demand for goods increased and new jobs were created. Technological progress increased not only people's purchasing power but also it resulted in the creation of new jobs. In other words, employment has benefited, either directly or indirectly, from technological innovations. Recently, the debate on "technological unemployment" has been reopened as a result of the downward employment trend that occurred in some advanced economies, especially in the United States of America. Many believe that the technological advancements of the third industrial revolution have had a potentially negative impact on employment levels. This, of course, raised the question: Does technology create or destroy jobs? Several authors have tried to estimate the impact of technologies on employment levels. However, there is no convergence of views. Therefore, it possible to determine with certainty whether the introduction of new technologies in production processes resulted in the creation or destruction of jobs. Nevertheless, studies and results of the researches relating to the consequences of technical progress on workforce composition came to the same conclusion. It is generally accepted that the introduction of digital technologies initially favoured high-skill workers, while replacing less-skilled ones. Low-skilled workers are more easily replaceable by machines than high-skilled ones. This is because they perform simple activities which can be easily automated. Technical progress, conversely, requires the contribution of workers who have the necessary skills to put machines into action. This phenomenon is known as skill-biased technological change. Starting from the 90s, however, medium-skilled employment declined. At the same time, employment for both high-skilled and low-skilled workers grew. This resulted in a polarization of the labour market. Therefore, the impact of technologies on workforce composition can no longer be explained through the use of a model that distinguish between skilled and unskilled workers. New hypotheses have been made to explain the recent phenomenon of the polarization of the labour market. The most important of these is known as the task-biased technical change (TBTC) or routine-biased technical change (RBTC). It decomposes job tasks into two categories: routine and non-routine tasks. Routine operations can be performed by machines while non-routine ones are very complex and, therefore, they are difficult to encode. As automation costs decrease, employers are encouraged to replace middle-skilled worker with machines in carrying out routine tasks. Non-routine tasks, conversely, withstand technological progress. The analysis that we applied to assessing technological impact on wage inequality pointed out that not everyone benefits from technological progress but, on the contrary, it creates winners and losers. Technological progress shift production frontier upward, increasing overall wealth. However, there is no guarantee that wealth is distributed fairly. In general, there are three ways for technological change to affect income distribution: first, through effects on employees, secondly, through the rewards earned by capital owners and, finally, through the rewards earned by "superstars". As seen from the above, technological progress increases the labour demand for non-routine workers while, at the same time, it decreased the labour demand for routine workers. If machines directly replace routine workers, the latter will see their wages to drop accordingly. Therefore, they are traditionally counted among those who are suffering from technological change. Nevertheless, those who have developed non-routine skills will see their wages to increase and, therefore, they will benefit from technological progress. If demand for high-skilled cognitive workers increases, wages will increase too. However, the impact of technological progress on non-routine manual workers' wages is ambiguous, because of two quite different phenomena. However, the impact of technological progress on non-routine manual workers' wages is ambiguous, because of two quite different phenomena.

The first effect is related to the fact that technological progress increases the workers' productivity and, therefore, their labour demand. The second effect is the result of the increase in the available workforce. In fact, routine workers replaced by machines will move towards non-routine manual works. Consequently, non-routine manual workers' supply will increase. Carrying out non-routine manual works requires a lower level of educational attainment compared to routine works. As a result of that, routine workers will be over-skilled and over-qualified in relation to the educational level required for the performance of non-routine manual jobs. This phenomenon is known as underemployment and it "*occurs when a worker is employed in a job that is inferior by some standard*".[301] Whereas the polarization of employment has taken place both in United Stated and in Europe, the polarization of wages is just an American phenomenon. Capital versus labour is the second set of winners and losers created by technological progress. "*Most types of production require both machinery and human labour (...) If the technology decreases the relative importance of human labour in a particular production process, the owners of capital equipment will be able to capture a bigger share of income from the goods and services produced*"[302]. This will force workers to reduce their wages or lose their jobs. Finally, one needs to consider that profits are not distributed equally across all companies. The best performer or superstar is capable of obtaining the highest compensations and increasing its market share at the expense of competitors, who, conversely, will hold a marginal share of the market. Since technology allows companies to improve goods' performance and quality, those who seize the occasion offered by digital technologies will be able to obtain a big share of the market. The result is disparities in income distribution between superstars and everyone else.

[301] McKee-Ryan, F. and Harvey, J. (2011). "*I Have a Job, But . . .": A Review of Underemployment*. Journal of Management, 37(4), p. 962.

[302] Brynjolfsson, E. and McAfee, A. (2011). *Race against the machine: how the digital revolution is accelerating innovation, driving productivity, and irreversibly transforming employment and the economy*. Lexington, Massachusetts: Digital Frontier Press, p. 30

Chapter 3: The employment scenario with the advent of Industry 4.0

Nowadays, we are standing at the dawn of a fourth industrial revolution that it is going to have a massive impact on productive sectors and on the economy as a whole. In contrast to the earlier industrial revolutions, Industry 4.0 will not simply rely on an individual enabling technology, but rather on a diversified set of interconnected technological infrastructures. Big data, artificial intelligence, augmented reality (AI), robotics, Internet of Things (IoT), and the additive manufacturing are just some of the numerous innovations characterising our age. Of course, not all economists agree that the fourth industrial revolution is underway. Among these, Jeremy Rifkin believes that the third industrial revolution has just bore its fruits. According to the author, "*the great economic revolutions in history occur when new communication technologies converge with new energy systems*".[303] For example, the author believes that the factors that contributed to the development of the first industrial revolution were precisely the invention of the press and the discovery of the coal-based energy. Similarly, the convergence between the electronic communications (telegraph, telephone, radio, and television) and the oil-based energy led to the development of the second industrial revolution. Klaus Schwab has a different idea. According to the World Economic Forum (WEF) CEO, there are at least three reasons why we can talk about a fourth industrial revolution. These are speed, scope and impact. The fourth industrial revolution is commonly referred to as Industry 4.0. The term "*Industry 4.0*", specifically, is being used to describe the application of the 21st technologies in the manufacturing sector. It was used for the first time at the Hanover Fair which took place in Germany in 2011. In Italy, instead, the term first appeared in the "*Piano Nazionale Impresa 4.0 2017-2020*" document submitted by the Minister of Economic Development, Carlo Calenda, in 2016. Many industrialized countries have taken the first step towards the adoption of the Industry 4.0 technologies. Their introduction into production processes is facilitated by country-specific policies. There is no one-size-fits-all model, and, consequently, industrial plans and the way these are

[303] Rifkin, J. (2012*). The Third Industrial Revolution: How the Internet, Green Electricity, and 3-D Printing are Ushering in a Sustainable Era of Distributed Capitalism.* The World Financial Review, p. 8.

implemented differ from one country to another. In particular, Germany, Italy, France, United Kingdom, China and United States of America (USA) policies are considered in more details in this connection. To analyze the employment impact of the 21st century technologies, several studies have been conducted. Various economists and consulting companies have tried to estimate the expected job gains and losses arising from the introduction of Industry 4.0 technologies into production processes. There is no convergence of views among economists with regard to the impact of the fourth industrial revolution on employment levels: some economists believe that Industry 4.0 will lead to more employment, other that more jobs will be created than lost. The routine-biased technical change hypothesis has been regarded by many economists as the major explanation of the polarization of employment. However, nowadays, the importance of the routine-biased technical change hypothesis is waning. This is because the introduction of the technologies of Industry 4.0 into production processes led to a blurring of boundaries between routine and non-routine task. Many of the activities classified as “non-routine” can in practice be automated and executed by machines and robots. For example, until very recently, it seemed impossible to automate the ability to drive a vehicle. Nowadays, Google’s driverless cars are used on the road. But, this is just one of the many examples that could be made on existing technologies’ ability to perform non-routine tasks. Autor et al (2003) model, therefore, is no longer valid and it cannot be used to forecast the impact that the next-generation technologies will have on workforce composition. Considering the recent technological developments, the two Oxford researchers Frey and Osborne modified the task model for modern times. While the task model states that computer can only perform routine work, Frey and Osborne's model provides that the human/machines substitution also applies to non-routine activities, to the exclusion of those that have engineering problems to computerisation. What the study reveal is that the next-generation machines will lead to the replacement of about 47% of the American workforce. In 2016, the CITI GPS, by taking Frey and Osborne’s model as its guideline, extended the analysis to the other OECD countries in order to the evaluate how susceptible are jobs to automation at a global level. By using data from the World Bank, the financial services firm showed that the 57% of the global workforce is at risk of automation. In particular, developing countries are deemed to be at greatest risk from the new wave of technological progress. However, even if these jobs are at risk of automation, it does not necessarily mean that they will be effectively automated. A number of factors should be considered in this respect. First, it is not possible to determine the way labour market will be changing given the difficulty of forecasting what job opportunities will be created in the future. Technological progress is improving at an exponential rate, therefore, for this reason, the appearance of effects which are not yet fully recognized cannot be excluded. Furthermore, even if a new technology becomes available, it does not necessarily mean that it will be used in the production process. In this respect, one must consider the economic viability of new technologies, the social acceptance and the regulatory framework. Another major criticism of Frey and Osborne's model was expressed by the economists of the Organisation for Economic Cooperation and Development (OECD). According to them, the occupation-based approach followed by Frey and Osborne tends to overestimate the number of jobs at risk of automation since many high-risk occupations contains tasks that cannot be automated considering the current state of technology. Then, the study wrongly assumes that work activities within the same occupational group are similar, without taking into account the fact that these are extremely varied, and they differ even between countries. A "*task-based approach results in a much lower risk of automation compared to the occupation-based approach*"[304]. In fact, compared to Frey and Osborne's provision, the OECD economists actually found that only the 9% of the American workforce is at risk of being replaced with the next-generation technologies. However, there seem to be agreement between economist that high-skilled workers are less likely to experience technological unemployment. Therefore, the best hope for economies alike is to upskill their workforce.

[304] Arntz, M., Gregory, T. and Zierahn, U. (2016). *The Risk of Automation for Jobs in OECD Countries A COMPARATIVE ANALYSIS*. OECD Social, Employment and Migration Working Papers, (189).