Polarization in Wage and Employment. The Role of Technological Change

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Abstract
The impact of technological change on the economy has been a controversial issue since at least David Ricardo's article in the 19th century. The labour-saving effect of new technologies has been evident at least since the Luddites movement that was violently opposed to the introduction of new technologies. Today, this issue is rapidly gaining interest as the spread of digital (and more recently of AI-related) technologies is changing the landscape of the labour market at an unprecedented rate. The displacement effect on the labour market caused by the introduction of new technologies has triggered a major debate on the impact of technological change on the labour market, whether or not it leads to polarisation of employment and wages. In addition, the introduction of new machines has transformed how production and work are organised, their social and cultural characteristics, and the way they interact with the institutional framework. An interdisciplinary approach to this phenomenon is therefore required as the new digital technologies have the capacity to bring about changes in the entire socio-economic system.

Keywords
Income inequality, innovation, wage polarisation, employment polarisation

Introduction

Over the last few years, the debate about the role and pervasiveness of technology in everyday life has become increasingly intense, in parallel with the proliferation of electronic gadgets and devices. Today, these devices are used for everyday transactions, for managing our relationships with public services such as banks, health institutions and public authorities in general, as well as our personal needs for communicating with friends, colleagues etc. This debate is evident in all social sciences. It takes on various forms depending on the different interests and methodologies that characterise each discipline. In the field of economics, scholars have been debating the determinants of inequality, focusing mainly on inequality in the distribution of income. Economists tend to neglect other dimensions of inequality or seem to downplay other facets that do not easily lend themselves to an explanation that can be analysed using quantitative methods.
In the field of economics, the debate on the role of the introduction of new machines and, more generally, technological innovation is not new. As early as 1821, David Ricardo had already pointed out the possible displacement effects that the production of new machines and their use in

manufacturing could have on the labour market (Ricardo, 1951-1973). Moreover, as of one of the more prominent interpreters of Ricardo's view pointed out, the British economist also mentioned the potential adverse effects of the introduction of these technological innovations on the level of real wages (Hollander, 2019). Even though the analysis of inequality in income distribution, as it is conceived today, was not on the agenda of economists at the time, it could be argued that Ricardo anticipated some terms of a debate, which would fully evolve almost two hundred years later. This debate also involved some of the most prominent economists of that period, such as Thomas Robert Malthus, John Stuart Mill and John Mc Culloch.[1]

At present, the current debate on the impact of technological change on income distribution can be traced back, for example, to the work of Katz and Murphy (1992) and Krueger (1993) in the 1990s. Both theoretical and empirical analyses have focused on the so-called skill-biased technical change (hereinafter SBTC). This approach demonstrates how the exogenous introduction of technological change may distort the demand for skills, favouring those associated with either high levels of education or long periods of in-house training. In this stream of economic literature, technical change was understood primarily as the intensive introduction of Information and Communication Technologies (ICT) into productive activities in both the services and the manufacturing sectors. This bias in the demand for labour towards highly skilled workers results in widening the wage gap between highly skilled and low-skilled workers (Atkinson, 2001).

Drawing on both the SBTC approach and on some empirical evidence pointing to increasing income inequality (OECD; 2011), some authors have attempted to analyse polarization of income distribution in Western economies (e.g., Autor (2015); Autor and Dorn (2013); Acemoglu and Autor (2011); Autor et al. (2003)). According to this approach, the distribution of demand for skills has been hollowed out in the middle causing the downgrading of middle-skilled jobs and the relative impoverishment of this segment of the labour force. This process, combined with the simultaneous increase in both the globalisation of markets for products and production factors and the outsourcing/offshoring of certain aspects of production have exacerbated inequality in income distribution, favouring especially the top 1% income share (Aghion and Griffith, 2022).

However, the hypothesis of polarisation[2] in the labour market and in income distribution is not unanimously shared in economic literature (Oesch, 2019). There is Eurocentric literature that claims that the hypothesis of polarisation does not apply to all the European economies. Others (e.g., Fernández-Macías and Harley, 2017) maintain that the role of technology has been overestimated and that other explanatory factors such as the globalisation of markets, the de-unionisation of the workforce and, more generally, the precarisation of employment, due to the weakening of the employment protection legislation in most European countries have been overlooked.

More recently, economic literature has focused on the introduction of Artificial Intelligence and robots in the production of goods and services. The overwhelming developments in research into Artificial Intelligence and its application in robotics have contributed to the development of machinery, hardware and software that are easily adaptable to production in all the levels and the sectors of the economy. This has had a disruptive effect on the entire economy. Not only has the introduction of these new machines transformed the organisation of production and work, but their penetration in the economic system has also changed the range of skills required and has replaced workers with machines for carrying out certain specific tasks. The theme of technological unemployment implied in Ricardo's analysis seems to have resurfaced two centuries later.

This paper is organised as follows. The first section deals with Ricardo's insights into the effects of the production and use of new machines in terms of output and the demand for labour. The second section looks at economic literature on the SBTC analysis and its polarising effects on income distribution.

[1] Despite this discussion regards a thoroughly different historical context, a brief introduction about it can shed light and provide interesting insights also on the present debate, as recently suggested by Hollander (2019).

[2] With polarization, we refer to the growth of employment in both the highest skill and lowest skill occupations, along with a decrease in employment in middle-skilled jobs.

Lastly, the third section concludes the review with few remarks about the very recent developments in the literature about the impact of robotisation on the demand for labour and income distribution.

1. Ricardo and the production of machinery

Hollander (2018) provides an effective overview of Ricardo's fluctuating positions on the effects of the introduction of machinery in production activities "on labourers". According to Hollander, the British economist's initial position was rather optimistic. The use of machines increases productivity and lowers the average price level, benefiting all sections of society. In particular, labourers would not have been adversely affected by the introduction of machines, as the level of both real wages and employment would not have been affected by this innovation[3].

However, in 1821 Ricardo (Hollander, 2018, Mokyr et al. 2015) changed his mind, perhaps influenced by the Luddites movement[4] that emerged at the beginning of the nineteenth century. Ricardo became convinced that machinery could replace labour and that the demand for labour could be eroded by the introduction of machines in production processes. This conclusion follows directly from the adoption of the wage fund theory, which postulates that wages are determined by the ratio between the circulating capital used to pay wages and the level of employment (Dobb, 1955). The circulating capital consists of food and necessities for the workers. However, if, in a given year, the economy produces machines, at the end of the year the amount of total output produced by the economy might well remain unchanged in quantitative terms. However, the composition of output will be transformed because the value of production will not only consist of food and necessities for workers, but also of the amount of machines produced. Consequently, in the following year, the amount of circulating capital needed to pay workers' wages will be reduced, and the level of employment will decrease as a result. Lastly, according to Ricardo (1817), the production of machinery partially displaces the production of food and necessities and makes some workers unemployed. In addition, Ricardo mentions that this structural change could also push down the real wages of employed workers.

Therefore, although the British economist does not explicitly address the issue of inequality in the distribution of income, in his theoretical approach the introduction of new machines to production processes can lead to the dismissal of some of the workers, without any substantial change in the level of output. Inequality in income distribution is due to an increase in production and profits, without a change in the overall level of wages. Interestingly, it is not the technical substitution of workers by machines that is cited as the reason for this dynamic, but rather the underproduction of food and necessities needed to sustain the workers. Later, Ricardo slightly modified his pessimistic view and qualified it.

Indeed, in a further refinement of his theory, Ricardo downplayed his pessimistic view about the introduction of machines. He explained that the process of introducing new machinery is extremely gradual and may not be detrimental to the level of employment (Ricardo, 1817). There is definitely, a certain amount of ambiguity in his positions. In the last adjustment of his approach to the analysis of the economic effects of the introduction of new machines, he seems, on the one hand, concerned not to discourage the use of new technological equipment but, on the other hand, he does not rule out the possibility that new machines may displace labour.

In conclusion, it can be said that Ricardo deserves credit for being the first economist in modern economic thought to have analysed the impact of technological change, understood as being the introduction of new machinery into the production processes. However, the perspective from which the British economist approached the subject distorted his conclusions and led him to neglect some of the possible consequences of technological change. In his approach, the undersupply of food and necessities for workers are the basis for the collapse in demand for labour. Although Ricardo was

[3] To see the original Ricardo's contribution, see Ricardo (1951-1973) and Ricardo (1817).

[4] The Luddites was a movement that in the XIX century in Britain opposed the introduction of machinery in the textile sector. In some cases, adherents of this movement destroyed the machines.

aware that capital goods, hardware and new machines could substitute workers in production processes, he seems to have downplayed this factor and not to have paid much attention to this dynamic. The lack of attention to production processes leads Ricardo to overlook the possibility that new machines may complement work activities and that workers may require new skills.

2. The change in the structure of labour demand

There is a vast amount of economic literature on the SBTC approach, and its comprehensive review goes well beyond the scope and purpose of this paper. As suggested by Chusseau et al. (2008) one could start from the discussion of the so-called Transatlantic consensus introduced by Atkinson in a couple of path-breaking papers (Atkinson, 2000, 2001, respectively pp. 6 and 438).
Atkinson (2000, 2002) shows that the Gini coefficient of income inequality began to rise significantly in most industrialised countries from the end of the 1970s. This rise in income inequality obviously occurred at different times in different countries, but it can be said that in the 1990s these episodes of rising inequality in income distribution affected all the most industrialised countries. However, it is important to emphasise that this dynamic was not uniform within each country but went through peaks and troughs without following any discernible trend. For this reason, according to Atkinson, it is more appropriate to talk about different episodes of increasing income inequality rather than a specific and statistically measurable trend. However, even though the paths of the dynamics of income inequality in the various western countries do not coincide, one factor unites all these economic systems. In these economies, the incidence of non-labour income on total income has increased. This was initially the result of the rise in long-term interest rates in all countries, and then it was driven by rising gross operating surpluses (including profits) in relation to wage and personnel costs.
Following Atkinson, in the 1990s, especially in the US, a consensus was reached among scholars about the causes of this substantial increase in inequality in income distribution in most Western countries. The dominant explanation was to be found in the widening of the wage gap between skilled and unskilled workers. The remarkable increase in the relative demand for skilled workers compared to unskilled workers not only widened the wage gap, but it also increased the likelihood of redundancy for unskilled workers. The debate was focused on why the relative demand for skilled and unskilled workers had shifted.
Different approaches were proposed (Atkinson, 2001). The first one is based on technological change and, in particular, on the intensive introduction of Information and Communication technologies (hereinafter ICT). This approach has become dominant among labour and industrial economists worldwide. An alternative strand of the literature has focused mainly on international trade theory by dropping some of the restrictive assumptions of the Heckscher-Ohlin model and introducing some more realistic ones (Atkinson, 2001). This approach sees the widening wage gap between high and low skilled workers as a consequence of the removal of barriers to both trade and the international movement of production factors (labour, capital, intermediate goods) between industrialised and less technologically developed countries.

2.1 The skill-biased technical change approach

The original formulation of Katz and Murphy (1992) assumes that technical change is exogenous (Chusseau et al. 2008). In the literature, technological change often refers to the introduction of ICTs. The exogenous introduction of these new technologies recombines the demand for labour services, which is divided into two distinct segments. The first (primary) segment is made up of highly skilled and well-trained workers. The second segment consists of low-skilled and poorly trained workers[5]. It is very common in economic literature to find that the gap between highly skilled and low skilled workers is proxied by the gap between highly educated and less educated workers. In general, highly

[5] The problem of assessing employee skill levels is chronic and it will not be addressed in this paper.

educated workers are those with at least a college degree, whereas less educated workers are those with a high school certificate.
According to the SBTC stream of literature, this restructuring of labour demand has changed the relationship between the demand for highly skilled and low skilled workers, giving rise to an increase in the former with respect to the latter. This dynamic has resulted in an increase in what is known as the skill premium, i.e. the wage gap between skilled and unskilled workers.
In addition, the rise in employment of skilled workers was accompanied by a significant upsurge of the unemployment rate of low-skilled workers, who have been severely disadvantaged by the introduction of ICTs in all the sectors of the economy. This segment of the workforce has been severely affected by the drastic changes in production processes in at least two different ways.
First, the introduction of ICTs has dramatically transformed how work is organised and how tasks are performed. Some tasks and skills were marginalised and removed from the remit of specific occupations, either to be incorporated in the remit of other occupations or removed from any stage of production altogether. This reshuffling of tasks and skills has caused a large number of occupations to become obsolete and new ones to emerge. Second, the introduction of the ICTs has encouraged delocalisation by outsourcing certain stages of production, especially towards countries that benefit from a comparative advantage due to low labour costs.
It is interesting to compare the impact of technical changes that occurred in the 1990s with the impact of technical changes between 1870 and 1970, because, despite there being remarkable similarities, the outcome is rather different. According to Frey (2019), during the twentieth century, technological progress was skill-biased and the relative demand for skilled workers increased relative to that for low-skilled workers. Nevertheless, contrary to what has happened over the last thirty years, the wage gap did not increase.
The reason for this can be found through a straightforward framework applied to supply and demand for highly educated and low educated workers. According to Tinbergen (1974) and, more recently, Golding and Katz (2010), the wage gap is closely linked to the race between education and technology. The logic underpinning this model is quite simple and deserves special attention. The idea is that technology is one of the main determinants in the demand for skills. As a result, at the microeconomic level, any technological innovation can entail a deep restructuring in the complex web of the skill structure in firms. Indeed, one has to take into account that, at a company level, the skills required and used are not the simple sum of individual skills but consist of a number of bundles of interacting skills, with complementarity relationships between them. Therefore, any technological innovation does not simply have an impact on individual skill, but it also has a significant impact on these groups of skills, giving rise to possible deep restructuring of this network of skill bundles (Goldin and Katz, 2010, pp. 189 and forward).
At a macroeconomic level, the analysis of the impact of technological change is rather complicated and requires drastic simplification, as it cannot be easily modelled using an analytical scheme. In general, the literature (Goldin and Katz, 2010) has adopted the segmentation between highly skilled and low skilled, which coincides with the split between workers with a college degree and workers with a high school certificate only. The macroeconomic scope of these analyses does not allow a finer disaggregation. The key point of this analysis is that as technological change progresses and innovations penetrate progressively into all sectors of the economic fabric, it also transforms the demand for skills. If the dynamics of skill supply does not match the changing demand for them, imbalances between demand and supply of skills may emerge. If the demand for skills induced by technological change outpaces the supply, the level of real wages for these skills will increase. Conversely, if the dynamics of the demand for skills resulting from technological change lags behind changes in supply, then the real wage for these skills is expected to fall and its growth dynamics to slow significantly.
As outlined by Frey (2019), the different dynamics of the wage gap between skilled and unskilled workers observed between 1870 and 1970 and over the last thirty years can be easily interpreted on the

basis of this straightforward demand/supply framework of analysis. Indeed, as Frey claims (2019), "From 1915 to 1960, the relative skills supply grew about 1 percent ahead of demand on an annual basis causing wage differentials to become compressed. This pattern stands in contrast to the post-1980s period, when the demand for skills outpaced their supply" (Frey, 2019, pp. 213). Basically, by contrasting the two episodes of skill-biased technological change, it can be argued that the different dynamics of the wage gap are due to the diverse dynamics of relative change between skill demand and supply.

Similarly, in their analysis of the American labour market between 1920 and 1950, Goldin and Katz (2010, pp. 92) show that the relative wage between highly educated and less educated workers decreased significantly. Therefore, since education is a proxy for the skills demanded and used in production, over this period one could observe a narrowing of the differential of the wage gap that divided the earnings of workers employed in skilled jobs from those of workers employed in unskilled jobs; these two variables tended to converge slowly. This convergence dynamic continued until the end of the 1970s, when it was interrupted. The two authors provide extensive and convincing evidence and state "[…] substantial agreement exists on the facts. These facts are, in short, that virtually *every* aspect of earnings by education, occupation, experience, age, and so forth has widened in the post-1970s era. For example, the wage premium earned by young college graduates (with exactly 16 years of schooling) relative to young high school graduates (with exactly 12 years) more than doubled from 1979 to 2005. Within-group wage inequality, known as "residual inequality," has also expanded. That is, the wages of individuals of the same age, sex, education and job experience are far more unequal today than 25 years ago (Goldin and Katz, 2010, pp. 50)".

It is important to emphasise that this scenario does not imply that from the end of the 1970s, one could observe a collapse in either the absolute supply of skills in the United States or the ratio of high skilled to low-skilled workers. As Goldin and Katz (2010) and Acemoglu (2002a, 2002b) highlight, the relative supply of high skills provided by workers with at least a college degree with respect to the supply of low skills provided by workers without a college degree has been steadily increasing since at least 1939.

Within the SBTC approach, Acemoglu (2002a) tells a different story. In his approach, technological change is not entirely exogenous to the production system, but it is endogenous. In this model, the exogenous increase in the supply of skills can induce a skill-biased technical change, which in turn, can fuel the wage premium and increase wage inequality between skilled and unskilled workers.

Interestingly, in his paper, Acemoglu (2002a) maintains that technological change accelerated the process of deunionisation, which has occurred in the United States since the beginning of the 1980s. In his model, Acemoglu claims that although deunionisation *per se* cannot directly account for the widening of the wage gap between skilled and unskilled workers, this does not mean that deunionisation does not play a role in the process of increasing wage inequality. The role of unions is mediated by technological change. The logic of Acemoglu's (2002a) model is quite complex but it deserves special attention because, as we will see below, it disputes the direct role of deunionisation in the slowing down of the dynamics of low skilled workers' wages. According to Acemoglu, union activity narrows the wage gap between skilled and unskilled workers. Nevertheless, skilled workers may find it convenient to join unions because their actions can improve productivity and training opportunities. When skill-biased technical change intervenes, the productivity gap between skilled and unskilled workers widens. As a result, the wage compression implied by the union action may become more costly for skilled workers and may even induce them to leave the union, thereby disrupting the coalition with unskilled workers. This can lead to dramatic institutional changes as the system of worker representation may collapse, giving rise to deunionisation or to the creation of a new union only for skilled workers. Ultimately, deunionisation could bring about a decline in the bargaining power of low skilled workers, with the framework of wage compression collapsing irreparably because of union intervention. In conclusion, not only can technological change, either exogenous or endogenous, have a significant impact on the wage differential between skilled and

unskilled workers, but it can also influence the institutional framework that regulates the labour market. This approach obviously does not allow us to understand whether the effects of institutional change due to technological innovation outweigh the effects of pure technological change on the wage gap, but it has the undoubted merit of highlighting the relationships between them and of shedding light on one of the possible causes of the widespread diffusion of deunionisation in most industrialised countries since the 1980s.

2.2 The task approach

Autor et al. (2003) introduced the so-called task approach, which can be considered as a refinement of the SBTC analysis[6]. While the SBTC focuses on skills and does not make a distinction between skills and tasks, this distinction is crucial in the task approach. This development was also worked out in order to take account of the sharp polarisation of labour markets that had emerged from empirical analysis, at least in the United States. The basic idea is that skills and tasks have to be considered separately. A task is the "unit of work activity that produces output" (Acemoglu and Autor, 2011, pp. 1118), whereas skills are the operational capabilities of the individual workers, which can be used to perform tasks. It is the performance of tasks, not the skills, that produces output. Each occupation can be defined as a set of tasks to be carried out, either individually or as a team. Tasks can be ranked in order of complexity, but there is not a one-to-one relationship between tasks and skills. The lowest level of tasks involves performing menial tasks that require a minimum amount of training. Some of these tasks cannot easily be automated, as they often require coordination and a certain degree of physical flexibility and strength. Intermediate level tasks involve the more complex tasks, being performed either by blue-collar or white-collar workers who have to follow specific and well-defined procedures. A higher level of training may be required than for low-level tasks. Unlike low-level tasks, these are more easily automated, even by using machinery that is not particularly sophisticated. Lastly, the third level of tasks involves work of an abstract and technical nature. A high level of specific and general formal training is essential in order to perform them, and their accomplishment cannot be easily codified and crystallised in specific procedures. The opportunity for automation is limited, but not impossible. It is important to emphasise the relationship between carrying out the task and the machinery used in production. In certain production processes, machines complement human activity in carrying out the tasks and it is impossible to do without them[7]. However, machines can replace humans in other stages of production.

The model assumes that there are three different levels of skills and, therefore, of workers, i.e.: low skilled workers, medium skilled workers and high skilled workers. Obviously, the higher the level of individual skills, the higher the level of individual productivity. Skills and, of course workers, form the supply side of the labour market. The key assumption of the model is that any task, from the most menial to the most complex, can be performed by any worker regardless of their skill level. This means that the substitution of skills across tasks is always technologically feasible. This does not mean that it is irrelevant who performs the tasks, because the higher the skill level of a worker, the higher is his comparative advantage in performing the task.

The maximisation process worked out by the employers consists of identifying two thresholds (I_L and I_H) that divide the full range of tasks. All the tasks below I_L are carried out by low skilled workers, the tasks above I_H are performed by high skilled workers and tasks that lie in between I_L and I_H are carried out by intermediate skilled workers. I_L and I_H are therefore determined endogenously and will change in response to changes in either the supply of skills or technology. Furthermore, these two factors, together with the two thresholds, will determine the structure of relative real wages.

One can conduct some interesting exercises in comparative statics. For example, let us consider the introduction of a skill-biased technical change, assuming that all other variables in the problem will

[6] See Acemoglu and Autor (2011) for a detailed review. The model outlined in their paper is a generalisation of Acemoglu and Zilibotti (2001).

[7] For example, a simple task such as driving is not easy without a van or a car.

remain unchanged. The effect of this structural change will be to increase the productivity of high skilled workers. This will result in a decrease of the level of I_H, so that some tasks that were previously carried out by medium skilled workers are now performed more productively by high skilled workers. However, this is not the only consequence of SBTC. In fact, not only will the optimisation of production processes lead to a decrease in I_H, but I_L will also decrease. This last consequence will lead to a kind of downgrading of medium skilled workers, as some of them will be assigned to tasks previously performed by low skilled workers. The effect on the framework of relative real wages is also interesting and complex. The relative real wage of high skilled workers will increase relative to the real wages of the other two categories of workers. At the same time, this exercise shows that the relative real wage of medium skilled workers will fall relative to that of low skilled workers.
It is important to note that SBTC will not only affect the structure of real wages but will also lead to a radical reorganisation of the distribution of tasks among the different occupations. Indeed, by reducing both I_H and I_L, SBTC could lead to the downgrading of some medium and high skilled occupations.

3. The polarisation of labour markets and the debate about European labour markets

3.1 Some useful indicators

Building on the task approach outlined in the previous section, Autor and Dorn (2003) discussed the polarisation of labour markets in the United States in detail. The unit of analysis is the job/occupation. The starting point of their empirical analysis is the introduction of the Routine Task-Intensity (RTI) index, which is an indicator of the content of routine tasks associated with each occupation. In the fourth edition of the US Department of Labor's Dictionary of Occupational Titles (DOT), published in 1977, they found the task requirements needed to measure the routine, abstract or manual task content of each occupation. By combining these three measures, the authors developed the RTI. By adopting a highly aggregated classification of occupations, the two economists produced Table 1, in which the rows indicate the occupations with a digit 1 level of aggregation and the columns show an assessment of three different task typologies and the RTI index for each occupation.

Table 1 – Task Intensity of major occupation groups

	RTI index	Abstract task	Routine task	Manual task
managers/prof/tech/finance/ public safety	-	+	-	-
production/craft	+	+	+	-
Transport/construct/mech/ mining/farm	-	-	+	+
Machine operators/ assembler	+	-	+	+
Clerical/ retail sales	+	-	+	-
Service occupations	-	-	-	+

The sign in each cell indicates whether the indicator is above (+) or below (-) the average value calculated for all six occupations. In Table 1, the occupations are ranked according to their complexity from the highest to the lowest. A couple of key points clearly stand out: a) the highest levels of the RTI are mainly concentrated in the middle skilled occupations. The lowest levels of both the RTI and the routine task index are calculated for the ends of the skill distribution (managers and service occupations). Routine intensity is inversely U-shaped with respect to skill distribution; b) the RTI is not influenced by either the manual or the abstract task content of occupations.
As the introduction of computers, ICT and, in general, automation techniques can be more easily and effectively used to perform routine tasks, from Table 1 it can be seen that automated processes and

techniques can replace middle skill occupations. This substitution process has also been facilitated by the availability and the price dynamics of these machines and techniques, which since the 1980s have become cheaper and cheaper.

3.2 The two dimensions of labour market polarisation

Labour market polarization has two main dimensions: a) job/occupation polarization and b) wage polarization. Job polarization refers to the increase of occupations at the extreme ends of the skill distribution with respect to medium skill jobs; wage polarization refers to the wage increase at the extremes of wage distribution: i.e.: the low wage and the high wage.

As far as these two dimensions of labour market polarisation are concerned, Author and Dorn's paper robustly highlights the following empirical evidence.

Employment polarisation. a) Since the 1980s, there has been a significant decline in employment with a high RTI: medium skilled occupation, possibly due to an intensive process of substituting workers in this segment of the workforce by automated production processes. This process has also been observed in low skilled occupations in the manufacturing sector, as this set of jobs mainly involves routine tasks that can be carried out by machines and automated production processes; b) Workers made redundant in the manufacturing sector have been mainly redeployed in low skilled jobs in the service sector, carrying out of non-routine tasks, as can be seen in Table 1. The introduction of computers and automated processes has neither complemented nor replaced these occupations, which have increased substantially since the 1980s; c) Consistent with the task approach outlined in previous paragraphs, SBTC has given rise to an increase in high skilled occupations. The introduction of computers has complemented the work of these kinds of job; d) As described by the task approach, the high routine task content of some middle clerical occupations has favoured the substitution of automated procedures for workers in these positions. These workers have been downgraded and reallocated to low skill occupations in service sectors. These jobs require the manual and non-routine tasks to be performed that may require physical dexterity and strength and are therefore difficult to automate; e) The decline in middle clerical occupations has hollowed out the skill distribution of jobs in the middle; f) The empirical evidence outlined in point e) combined with that in points c) and b) has shaped the relative dynamics of occupations since the 1980s. The growth rates of occupations at the two extremes of the skill distribution have increased substantially, while those in between have contracted appreciably. As a result, growth rates in the skill distribution of jobs exhibit a U-shaped profile. In this way, employment has gone through a long phase of polarisation.

Wage polarisation. As described in the analytical framework of the task approach, SBTC could radically change not only the structure of employment, but also the matrix of relative wages. Consistently with structural changes in employment, the empirical analysis shows (Autor and Dorn, 2013, Goldin and Katz, 2010, Acemoglu, 2002b): a) The increase in demand for low-skilled occupations led to an increase in wages for this segment of employment, especially with respect to wages for medium-skilled jobs; b) Likewise, wages for high skilled occupations have risen significantly; c) Wages for medium skilled occupations have fallen as a result of the decline in labour demand for these jobs; d) Wage polarisation resulting from points a), b) and c) fits into with employment polarisation.

3.3 The debate about polarisation of labour markets in Europe

The empirical test of the hypothesis of polarisation of labour markets discussed in the previous paragraph was based on the analysis of US data. Analogous analytical procedures have been applied to a large set of 16 Western European countries[8] for the period 1993-2010 (Goos et al. 2014; Goos et al. 2009) using the European Community Household Panel (ECHP) and the European Union Statistics

[8] The European countries are as follows: Austria, Belgium, Denmark, Finland, France, Germany, Greece, Ireland, Italy, Luxemburg, Netherlands, Norway, Portugal, Spain, Sweden and the United Kingdom.

on Income and Living Conditions (EU-SILC). Based on a theoretical ground substantially analogous to that developed by Acemoglu et al. (2011), these analyses confirm that polarisation of the employment structure can be seen not only in the United States, but also in most other Western countries.

There is no consensus on the prevailing polarisation in European labour markets. Fernández-Macías (2012) criticises the arguments developed using the task approach on both theoretical and empirical grounds, by providing quite different evidence. From a theoretical point of view, Fernández-Macías notes that the task approach completely ignores the institutional context in which SBTC occurs. Fernández-Macías points to the lack of attention to both the power relations in the work/labour market and the regulatory systems within which work activities are framed. Basically, according to Fernández-Macías, the task approach is driven by technology and focuses mainly on labour demand. Occupations are defined by technology without the intervention of workers (Fernández-Macías, 2012, pp. 160-163).

However, the main critiques and discrepancies between the two approaches concern the empirical analysis. The unit of analysis of Fernández-Macías' approach is the job, as in the task-based methodology. The main difference is in how the jobs are ranked. In the task approach (Goos et al. 2014) it depends strictly on the 1993 mean European wage. Therefore, not only do Goos et al. (2014) imply that all European countries have the same wage structure, but they also assume that only the level of real wages determines job quality. Therefore, jobs are ranked only on the basis of wages. This result in three sub-groups of occupations: a) eight highest-paid occupations; b) nine medium-paid occupations and c) four lowest-paid occupations. Respectively, these three segments account for 28.78%, 48,98% and 22.25% of occupations[9].

Fernández-Macías has taken a rather different approach to job ranking. In his approach, the level of wage is not the only indicator of the quality of a job. Job quality is a multi-dimensional notion and the average wage associated with each occupation cannot be considered as the unique determinant of its quality. Of course, at the macroeconomic level, developing an effective and single indicator of job quality can be quite complicated and give rise to inaccurate and unhelpful measures. Accordingly, Fernández-Macías has constructed two different indicators of job quality. The first is the standard average wage level calculated for each occupation; the second is the average educational level found for each occupation. Furthermore, unlike Dorn at al.'s method, Fernández-Macías does not use the mean European wage level for each occupation, but he calculates the mean wage level per occupation in each of the European countries considered. He then carries out the empirical analysis based on these two indicators for the period 1995-2007. The two indicators give the same result for each country, even though the intensity of the two indicators for each country can be significantly different: a) according to both indicators, the United Kingdom, Germany, France, Belgium and the Netherlands exhibit a polarisation of occupations, b) in Italy, Spain, Portugal, Greece and Austria, the two indicators show the predominance of a significant increase in mid-position occupations (mid-upgrading), c) in Sweden, Finland, Ireland, Luxemburg and Denmark, there is evidence of upgrading in occupations; in these countries, there has been an increase in the number of jobs associated with the highest levels of the labour market over this period.

Oesch and Piccitto (2019) follow a research strategy similar to that of Fernández-Macías and for a smaller sample of countries; they reject the hypothesis of polarisation of a few labour markets in Europe. Germany, Spain, Sweden and the United Kingdom are analysed for the same period between 1992 and 2015. The two sociologists developed four different indicators of job quality for their analysis. The first two indicators coincide with those developed by Fernández-Macías; the third indicator is an index of job status and prestige, and the fourth indicator is a proxy of job satisfaction. By analysing all four indicators, Oesch and Piccitto (2019) conclude that the top-ranked occupations

[9] Fernández-Macías calculates that by simply aggregating sub-groups of occupations equally, the results can be quite different.

have grown more intensively than the others and that this period has therefore been characterised by an upgrading of the employment structure, at least in these European countries.

4. The Robotisation of production. Some preliminary observations.

According to the ISO 8373 vocabulary, industrial robots can be defined as an "automatically controlled, reprogrammable multipurpose manipulator programmable in three or more axes" (ISO, 2021), which can be either fixed in place or mobile for use in industrial automation applications[10].
The literature on the impact of robotisation in labour markets has grown rapidly over the last few years in parallel with the strong penetration of robots in productive activities in both the industrial and the service sectors. However, as far as the effects of robotisation on the level of wages and employment are concerned, it cannot be said that either a broad consensus has already been reached or that a limited number of alternative and well-defined positions are in conflict.
According to an analysis by Acemoglu and Rastrepo (2019), automation / robotisation has three distinct effects. First, it increases productivity, giving rise to an increase in the demand for labour to perform non-automated tasks. Secondly, automation causes a contraction of labour as it displaces human labour from performing specific tasks. Thirdly, it can create new tasks. The possible negative effect of automation on employment can only be offset by the creation of new tasks resulting from the introduction of new technologies or from productivity gains at the macroeconomic level. Using data on the United States, the two authors also found (2018) that the introduction of robots has a negative impact on production levels.
Graetz and Michaels (2018) develop a less pessimistic view. In their paper, they found that robots improve productivity and contribute to wage increases, but only have a negative effect on the level of low-skilled employment, while the effect on total employment is not statistically significant.
Dauth et al. (2021), using data on Germany, provide an extremely articulated analysis. By adopting the theoretical perspective of Acemoglu, Rastrepo (2019), they emphasise that although the effect of robotisation on total employment is zero, the introduction of robots leads to a significant reallocation of both tasks within the manufacturing sectors and jobs between sectors (i.e.: from manufacturing to services sectors). This recombination of tasks implies the reallocation of workers to new and different tasks and the upgrading of workers' skills. These effects are mirrored by the effects on wages. Interestingly, Dauth et al. (2021) claim the importance of labour market institutions (unions and labour laws) in the outcome of these complex processes of job, task and skill reallocation.
Finally, in a paper that discusses evidence on European countries, Klenert et al. (2022) found a positive correlation between the use of robots and total employment, and no significant impact on low skilled employment.

5. Conclusions

The polarisation of employment and wages is a highly relevant phenomenon that has many implications that are obviously related to how economic systems adapt to the very pervasive technological change. However, there are strong social, political and cultural dimensions that are heavily influenced by changes in the way workers and their job are perceived by society at large. The social dimension of employment is relevant both to the way work is viewed within the society and to the way in which workers are considered as an important part of the political and cultural dimension of societies.
For these reasons, the impact of technology on society has been highly debated since the origins of contemporary social science, and its effects have been analysed thoroughly, not only in the field of economics but also by all the other social sciences. This is because the introduction of technological

[10] Service robots are defined as "robot that performs useful tasks for humans or equipment excluding industrial automation applications".

innovation has always affected all interrelated spheres of the social life, such as work activities and the effort involved, the value of work, the way people interact, and the way political power is exercised and controlled.

From an economic perspective, the analysis of the introduction of new technologies in the production of goods and services has always been tightly intermingled with the study of the political consequences that these innovations might have. A clear example of this close link is the case of the Luddites movement in the 19th century. Maybe for the first time, a political movement blamed the introduction of new technologies and machine as a potential factor in the destruction of jobs. The impact of the introduction of new technology and machinery on employment has been the focus of a strand of economics ever since.

In the light of these considerations, the first important conclusion that can be drawn from this brief review of the literature on the relationship between technology and income inequality/distribution is that any structural change, such as the introduction of technological innovations, has an overall effect that is not limited to the economic sphere. Indeed, it affects (and is affected by) many other dimensions of the social fabric, from the heterogeneity of the behaviour of economic agents, to their cultural and social constituents, to the components of the institutional framework, and, in general, to the political *zeitgeist*. A clear example of these differences can easily be seen in the different reactions to the introduction of ICT in the 1990s between the American and some European labour markets. The different impact of the introduction of ICTs on the distribution of income between the US and some European countries confirms the interrelationship between technology and the institutions that regulate both the markets and the internal organisation of productive factors in businesses. This is due to the fact that adopting new technologies is never (we could even argue that it cannot be) a neutral top-down operation, but it always interacts with the socio-economic fabric that absorbs and shapes it. As a result, the non-neutrality of technology and its continuous interactions with the institutional domains could pave the way to a relevant role for policy interventions. This observation draws attention to the role that industrial policies aimed at promoting innovation in firms play in the performance of labour markets and, in particular, in determining the distribution of earnings. In order to address specific objectives in the labour market, industrial policies should be integrated with labour policies to complement them and avoid unintended effects.

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