The employment effects of digitalisation—a literature review

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Contents

1. Introduction

In the present work we aim at providing a review of the literature on the most relevant contributions related to the relationship between current digitalisation processes developing across economic systems and their impact on employment. Digitalisation processes are driven by the convergence of a number of technologies and internet infrastructures, developed independently over the last decade, that have recently become available all together, thus offering a wide range of possible applications.

According to some scholars digital technologies and infrastructures that can be seen as general purpose technologies (GPTs) (Bresnahan and Trajtenberg, 1995; Helpman, 1998; Beaudry et al., 2016), which means that they can spread in several different economic sectors, providing not only the possibility to enhance the efficiency of the existing products or processes, but also to transform them radically. A few examples of GPTs provided by the authors are the steam engine, semiconductors and the IT revolution that, in the words of Helpman (1998, p. 23), has been "changing

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product design, production, marketing, finance and the organization of firms [. . .] creating a wide range of new products incorporating hard coded chips, computers, and/or software."

The high level of pervasiveness that GPTs have may lead to industrial revolutions, as happened in the past or, at least, to a change in the founding principles of the economic system.

According to some authors (Degryse, 2016; Valenduc and Vendramin, 2016) there is still no consensus on the founding principles of the digital economy, but there are some key features of the new economic system that can be drawn from the literature produced so far:

1. Digitalised information has become a strategic resource, and the network has become the chief organizing principle of the economy and society as a whole. A new generation of digital technologies are now generating unprecedented quantities of data and providing the tools needed to harness this asset and leverage its value.
2. The digital economy—along with an ever increasing range of tangible and intangible economic activities—follows the principles of growing returns (positive network externalities) and zero or quasi-zero marginal costs.
3. New business models are springing up to take advantage of two-sided markets and the platform-based economy, particularly those involving collaboration or sharing, and new competitive dynamics—dominated by the 'winner takes all' model—are taking hold in markets for digital goods and services.
4. A newly emerging model of industrial production (sometimes referred to as 'Industry 4.0') involves short production runs of mass-customised goods, the global fragmentation of value chains, the networking of productive capacities and the blurring of boundaries between producers, sellers and consumers on the one hand and industry and the services sector on the other.
5. Profitability calculations for technological investments have been revolutionized by a plunge in the cost of hardware and software paired with a leap in their performance and productive efficiency. Nevertheless, a cause-and-effect link between technological innovation and productivity gains has not yet been directly established, and the relationship between technology and productivity is still heavily dictated by society's take-up of innovations and organizational changes within companies.

Before illustrating the main contributions related to the impact of digitalisation processes on employment we believe it is necessary recalling that this theme is part of a larger discussion on the existing relationship between innovation and employment. The literature on this big issue is very wide and we will not have the possibility to provide a full review of it, however we believe that the current debate on the relationship between digitalisation and employment is not totally new in itself, but can be seen as part of a wider discussion. There are of course some new features strongly related to the most recent technological advances and we will take them into consideration later in the paper.

The present work is organized as follows: Chapter 2 will provide a literature review on the relationship between innovation and employment, Chapter 3 will focus on the recent literature on the relationship between digitalisation and employment, Chapter 4 will provide some conclusions and directions for future research.

2. Innovation and Employment

The relationship between technical change and innovation is very complex and has been studied by many economists for a long time. As we do not have the possibility to provide here a complete review of this rich literature, in this section we present only the most relevant contributions and key differences between them.[2]

Even in the classic economic contributions it is possible to see that authors tackled the issue of the relationship between innovation and employment. For example, James Steuart addressed the problem of unemployment caused by mechanisation, Adam Smith pointed out how machines could help favour the division of labour and underlined the labour-saving effects. Addressing the loss of jobs and de-skilling in the labour market brought about mechanisation at the beginning of the nineteenth century in England, David Ricardo believed that the economy could compensate the negative employment effects, however he also stated that: "The opinion, entertained by the labouring class that the employment of machinery is frequently detrimental to their interests, is not founded on prejudice and error, but is conformable to the correct principles of political economy" (Ricardo, 1951, p. 392), thus recognising that machines could cause unemployment. Karl Marx was highly critical towards the compensation theory, he believed that the rising unemployment, the de-skilling processes and loss of control by workers on their own work he observed was due to mechanisation.

The issue of the role of technology in creating or destroying employment has been addressed by modern contributions, in different streams of literature, that we will briefly recall here. Pianta (2005) offers a summary of approaches to innovation and employment, as reported in Table 1.

The main differentiating element between the approaches to the issue is related the ability (or not) of product and labour markets to get back to the equilibrium after a shock (often exogenous). Starting with the mainstream approach, innovation is treated as an exogenous change in technology, which leads to a change in the production function and eventually to economic growth and employment. In the modern "new growth theories", the perspective towards innovation is different as is seen a source of endogenous growth. Looking at the labour economics studies, the focus is more on changes in employment and wages looking at different elements affecting labour markets, where technology is considered only secondary. Despite the efforts of some contributions, in these perspectives technological change occurs in a context of a general or partial equilibrium, therefore assuming that the system will often have the ability to adjust. In particular with regards to unemployment, this is always considered to be temporary as the assumption is that there will be a wage adjustment, accepted by workers, that will restore the equilibrium. According to these perspectives, unemployment cannot be structural and there is no technological unemployment; in case reality shows different trends, this is due to rigidities in the labour markets such as collective bargaining or minimum wage. Moreover, in these studies there is no distinction between types of innovation, as technical change is only seen as process innovation.

As shown in Table 1, a radical different perspective is the disequilibrium one, where there is no assumption that the economic system automatically adjusts to (often exogenous) shocks. Instead, when radical new technologies emerge leading to a change of the technological paradigm (Dosi, 1982), such as for example the diffusion of ICTs, a large amount of jobs can be created

[2]For reviews of theoretical approaches, see Meyer-Kramer (1992); Vivarelli (1994); Petit (1995).

Table 1: A summary of approaches to innovation and employment

Main research questions **Does technology crate or destroy jobs?**	General approach	Major streams of literature and key findings	Key assumptions and methodology	Main level of analysis
Equilibrium of product and labour markets				
What is the amount of jobs created/lost	Labour economics	Job demography and flexibility of labour markets	Product and labour markets are in equilibrium	Firms, industries, macroeconomy
What is the shill composition What is the structure of wages		Technical change favours more skilled workers, replaces the unskilled, exacerbates inequality Supply of educated workers shapes technical change Technological unemployment is irrelevant	The absolute level of job lost/gained is irrelevant Complementarity beteen IVTs and high skills	
What are the returns from innovation	Growth	Technology, productivity, growth, employment: innovation may raise the natural rate of unemployment	Standard production function, focus on process innovation	Industries, macro
What is the innovation input to growth	New growth theory	Endogenous innovation, growth and employment may happen	Innovating and non innovating firms, spillovers, focus on process innovation	Macroeconomy
Disequilibrium perspectives				
What is the type of innovation What is the amount/nature of unemployment	Evolutionary	Technological opportunities, variety, regimes: firms'strategies and industries outcomes are different	Innovation brings disequilibrium in markets New product markets emerge	Firms, industries
What are the structural factors What are the demand factors	Neo-Schumpeterian	Techno-economic paradigms and long waves: mismatches can lead to unemployment	Radical innovations, pervasiveness, diffusion of new technology systems and ICTs	Industries, macro
What are the distribution effects What are the institutions	Structural	Sectoral composition of economies: specificity of innovation and demand, different job results	Innovation is differentiated: contrasting effects of new products and processes Industries are different, demand is important	Industries
	Regulationist	Macromodels for testing indirect effects of innovation: compensation mechanisms may not work	Countries are different, institutions are important	Macroeconomy

Source: Pianta (2005, p. 570)

or destroyed. From this perspective, estimating the amount and typologies of jobs that may be destroyed or created becomes a very complex task as this depends on the process of diffusion and adoption of the new technological paradigm and, as it offers new opportunities, may also cause a skill mismatch. Therefore, according to the disequilibrium perspective, technological unemployment exists and it is due to the slowness of labour markets in the "adjustment process". The "adjustment process", that is key to this theoretical perspective, is the interaction of society and new technologies where both react and change by means of the opportunities offered by the other.

We recall here in particular the seminal work of Schumpeter that influenced the studies later produced on technological change. Differently from previous and contemporary economists like neo-classical and Keynesian, Schumpeter placed technological progress at the centre of the economic dynamics, identifying in innovation the major source of disequilibrium in the economic system. There are two reasons, according to Schumpeter, why innovations can be disruptive for the economic system as whole. First, innovations do not occur harmoniously across the economy but instead they tend to concentrate in key sectors, leading to structural adjustments between sectors. Secondly, the introduction and exploitation of innovations brings to economic cycles, with long periods of growth followed by decline. This happens because, at the beginning, when innovation is definitively introduced after a period of "false starts", this is followed by a period of rapid growth accompanied by imitation, which leads to a large number of new firms entering the market trying to exploit the new opportunities. Later, this "swarming effect" brings to market saturation and the economic expansion begins to slow down. Therefore, not only technological unemployment exists in Schumpeter's view but is also consistent with his model: "(Economists) have a habit of distinguishing between, and contrasting cyclical and technological unemployment. But it follows from our model that, basically, cyclical unemployment is technological unemployment [...] Technological unemployment [...] is the essence of our process and, linking up as it does with innovation, is cyclical by nature. We have seen, in fact, in our historical survey, that periods of prolonged supernormal unemployment coincide with the periods in which the results of inventions are spreading over the system and in which reaction to the by the system is dominating the business situation, ads for instance, in the twenties and in the eighties of the nineteenth century" (Schumpeter, 1939, pp. 515-16).

Despite the significant differences between the equilibrium and disequilibrium perspective, the theories belonging to both approaches agree on the fact that the adjustment period to technical change is not automatic and may take a long period and not being that smooth. Even in the most extreme neo-classical models is recognised that equilibrium in self-adjusting markets is eventually reached but with some problematic consequences. The opposite of this extreme position can be seen in authors such as Perez (1983) and Boyer (1988) who believe depression is caused by a mismatch between the new emerging technological paradigm and the existing social and institutional framework. In their view, the mismatch can be resolved only via political intervention that aims at changing the institutional context that may lead to changes in education, industrial relation systems, capital markets etc.

More recent empirical studies went beyond the analysis of innovation taken as whole but distinguished between different types of innovation, primarily product, process and organisational innovation, trying to measure the actual impact on employment of each of them. We will present some of the key contributions from this branch of empirical literature in the following section. Before doing so we recall that large attention has been paid by scholars also to the ways innovation spread across the economy and to those factors that may influence, accelerating or slowing down such diffusion. According to Hall (2003, p. 2), “it is safe to say that without diffusion, innovation would have little social or economic impact. In the study of innovation, the word diffusion is commonly used to describe the process by which individuals and firms in a society/economy adopt a new technology, or replace and older technology with a newer. But diffusion is not only the means by which innovations become useful by being spread throughout a population, it is also an intrinsic part of the innovation process, as learning, imitation, and feedback effects which arise during the spread of a new technology enhance the original innovation.” Ultimately all these elements influence the rate of adoption and use of innovations across the economy therefore influencing the impact on employment.

2.1. The quantitative effects of innovation on employment

In the current section we present the most relevant empirical evidence related to the quantitative impact of innovation on employment, usually measured in terms of number of jobs or number of hours worked. We will do so mainly by following the scheme and summary of these results offered by Pianta (2005), presented in the table below. As outlined in the table, the quantitative effects of innovation on employment can be studied at three different levels: at the firm, industry or macroeconomic level.

Beginning with studies conducted at firm level, should be noted that there is a large number of analyses on the issue, mainly conducted making use of panel data related to a number of, often manufacturing, sectors at national level (for reviews see Petit, 1995; Chennells and Van Reenen, 1999; Spiezia and Vivarelli, 2002). Overall, the results of these studies show positive effects of innovation on employment, as firms that introduce product, process, organisational innovations tend to be more competitive, more productive, expand their markets and therefore they grow faster, with positive implications on the number of jobs. The weakness of these studies is that they show what happens to the groups of firms analysed but they say anything about the whole economy. In other words, if the growth of the innovative firms is made at the expenses of competitors, the overall system effect may be negative.

In order to overcome the limits in generalisation of the fim-level studies, scholars focused on the effects at industry level, that take into consideration both the direct consequences at firm level, as in the studies mentioned before, and the indirect effects that may arise within the industry.

The industry level is considered by scholars who applied it as the “most satisfactory level of analysis, as it is able, on the one hand, to differentiate between the variety of technological regimes and strategies and, on the other hand, to bring in the demand dynamics of specific sectors, taking into account country differences in economic structures” (Pianta, 2005, p. 579). Most of the empirical studies show that product and process innovation have opposite employment effects: product innovation, in particular if developed in contexts of high demand growth, have positive effects, whereas process innovation, often adopted to increase productivity and reducing labour costs, leads to job losses. These results have been reached both analysing manufacturing and services. The sector-level analysis provides then a different picture as compared to the one offered by the firm-level analysis, in particular in the case of studies on Europe. Empirical evidence show that product innovation had positive impact on employment, but at the same time, the constrained demand due the slow economic growth since the 1990s and the increase in international competition led companies to apply labour-costs-saving strategies, thus enhancing process innovations and

Table 2: Effects of innovation on the quantity of employment: selected empirical studies

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 relations survey	Positive
Brouwer, Kleinknecht and Reijnen, 1993	Netherlands	1983-88	Cross firm, manufacturing	Dutch survey	Negative Positive with product innovation
Meghir, Ryan and Van Reenen, 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, 2001	5 EU countries	1989-93	Cross sector 21 manufacturing industries	Innovation survey	Overall negative Positive if product innovation
Antonucci and Pianta, 2002	8 EU countries	1994-99	Cross sector 10 manufacturing industries	Innovation survey	Overall negative Positive if product innovation
Evangelista and Savona, 2002, 2003	Italy	1993-93	Cross sector service 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 and process innovations	Differentiated by compensation 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

Source: Pianta (2005, p. 577)

restructuring.

The macroeconomic studies take into consideration a larger number indirect effects that act in the whole economic system and can lead to different results from those outlined above. In particular scholars who studied employment effects of innovation focused on process innovation, that is often labour-saving thus leading to an increase in unemployment. Vivarelli (1995) and Simonetti et al. (2000) further explore this issue taking into consideration the existence of six compensation mechanisms that may compensate for the negative impact of process innovation.

1. Compensation via decrease in prices
   "The introduction of new process technology is usually associated with increases in labour productivity and therefore a reduction in unit costs. In a competitive economy, the decrease in costs also produces a reduction in the prices of the existing goods which, in turns lead to an increase of the demand for goods and therefore an increase in the demand for labour." (Simonetti et al., 2000, p. 28)
2. Compensation via decrease in wages
   This is the typical adjustment process of neo-classical approach where technological unemployment is resolved via the decrease in wages that lead firms at hiring more workers (the Phillips relationship). This argument is based on strong assumptions: that companies can choose their capital intensity and that the decrease of wages will not have depressive effect on demand.
3. Compensation via new investment
   Following the work of Schumpeter, innovators can take advantage of monopoly positions, thus benefitting of extra profits that can be re-invested and thus creating more employment. However, profits can be hoarded instead of invested, and if, invested, could be in new capital at the expenses of employment. Moreover, workers might succeed in appropriating of a part of profits via an increase in wages which would lead to a reduction of employment.
4. Compensation via new products
   As we have seen before, new products may lead to new activities and new markets, with positive (direct) effect on employment. Moreover, "the increased Schumpeterian competition generated by new products on the market might drive price down and reinforce the compensation mechanism via decrease in price. The positive employment impact of product innovation may be mitigated by the substitution effect of new products versus mature goods." (Simonetti et al., 2000, p. 29)
5. Compensation via new machines
   When new capital goods are introduced, this generates a positive effect for machines' producers. However the compensation effect takes place if there is a net effect, in other words if new capital goods are introduced with additional investment, not only as a substitution of the old production lines.
6. Compensation via additional income
   This mechanism is basically the Keynesian one, where innovations bring more income via an increase in profits or wages, thus effective demand increases higher profits and wages increase consumption. However, as seen above, this mechanism is incoherent with both the compensation effect via new investment via decrease in wages.

Overall the studies that examined if and how these mechanisms work reached different results, sometimes contrasting, mostly due to the lack of data and the complexity in the construction of the model which has to consider all the relevant relationships. “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 of price reductions are greater.” (Pianta, 2000, p. 582)

Finally, as presented in Table 2, the relationship between innovation and employment has been studied also by means of simulation studies (Leontief and Duchin, 1986; Whitley and Wilson, 1982; IPTS-EPSO, 2001). According to the work done by Leontief and Duchin (1986, p. 12), “that the intensive use of automation will make it possible to achieve over the next 20 years significant economies in labor relative to the production of the same bills of goods with the mix of technologies currently in use. Over 11 million fewer workers are required in 1990, and over 20 million fewer in 2000 [...], this represents a saving of 8.5 and 11.7%, respectively, of the reference scenario labor requirements.” Differently Whitley and Wilson (1982) tried to quantify some compensatory effects on employment that could offset displacement effects brought about by technological change, showing that both job losses and gains were possible, depending on the assumptions on the speed of diffusion and users’ demand of microelectronics.

Overall the results of these studies, although very interesting as they show different alternative scenarios and related projections, present some weaknesses: in case they use a general equilibrium model (IPTS-EPSO, 2001), they do not identify technological unemployment while, in case of the use of input-output model (Leontief and Duchin, 1986), do not identify compensation effects. Moreover, they are based on strong assumptions on the productivity-enhancing effects of process innovation. Finally, as in the case of Whitley and Wilson (1982) the weak element sits in the assumptions made on the diffusion and on users’ demand.

According to Pianta (2005, p. 583), trying to summarize the literature considered so far, “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 innovating 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 determinants of the results obtained in empirical studies.” Finally should be noted that the studies examined above are all referred to national economy and the relationship between employment and innovation has not be addressed in a global perspective, which could lead to new and different results.

2.2. The qualitative effects of innovation on employment

A large branch of labour economics literature, focused more on studying the qualitative effects of innovation on employment, rather than the quantitative ones. The interest towards this issue was partly due to the fact that scholars adopting the equilibrium perspective did not recognise the existence of technological unemployment, as we have seen before, therefore instead they looked for changes in the characteristics of labour markets. In particular, a large number of studies have been produced in the US, pointing out that the technological evolution occurred since the 70s favored the growth of skilled workers who replaced unskilled labour, thus eventually increasing wage inequality. Some of the key contributions of the so called skill-biased-technical-change (SBTC) literature, review in Acemoglu (2002) are from Krueger (1993), who published an influential paper titled *How computers have changed the wage structures*, Greenwood and Yorukoglu (1997, p. 87) who stated “setting up, and operating, new technologies often involves acquiring and processing information. Skill facilitates this adoption process. Therefore, times of rapid technological change advancement should be associated with a rise in the return to skill.”

In his review of this branch of literature, Acemouglu points out that although the large consensus on the bias of technical change towards skilled labour, further supported by the technological changes brought about ICTs, is indeed a 20th century phenomenon. In the 19th century, the innovation contained in factories and production lines replaced skilled artisans, showing of being unskilled-bias. “The experience of the nineteenth and early twentieth century led [. . .] to argue that technical change was ‘deskilling’—a major purpose of technical change was to expand the division of labour and simplify tasks previously performed by artisans by breaking them into smaller, less skill-requiring pieces.” (Acemoglu, 2002, p. 9) What are the determinants of the different trends in the two analysed centuries? According to this author, the early nineteenth century was characterised by skill-replacing developments because the increased supply of unskilled workers in the English cities made the introduction of these technologies profitable. Differently, “the twentieth century was characterized by SBTC because the rapid increase in the supply of skilled workers has induced the development of skill-complementary technologies.” (Acemoglu, 2002, p. 64) In this contributions, there is a sort of complementarity between technological and skill change, where it is not only the supply of skills that influence technical change, but it also the other way around. Acemoglu and Autor (2011, p. 1044) point out: “the starting point [. . .] is the observation that 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 same authors suggest that, on the basis Tinbergen’s (1974, 1975) work the relative demand for skills is linked to technology, and in particular to the skills bias of technical change.

In his review of the literature on the issue Pianta (2005) illustrates that one stream of work (Berman et al., 1998) compares the effect of technology with those of increased international trade, finding that technology accounted for the largest part of the reduction on less-skilled workers, while another stream (Doms et al., 1997) showed that new technologies are adopted extensively in plants with more skilled workers, but do not increase the demand for skills. However, he also points out that “when more refined measures of skill are used, the evidence of skill-bias is less clear.” (Doms et al., 1997, p. 584)

Radically different conclusions from the SBTC perspective are reached by Howell (1996) who disagrees with the idea of a link between computerisation, upskilling and wage inequality, showing that the skill structure in the US changed significantly between 1973 and 1983 but little change took place later, when ICT started to diffuse widely.

The last point we would like to make in present section is that not only the impact on skills brought about by technological innovation have been studied but also those determined by organisational innovation. A large number of studies on European Countries have shown that organisational innovation is often more important than the technological one in modifying companies’ structures and the associated skills (Caroli and Van Reenen, 2001; Greenan, 2003; Piva and Vivarelli, 2002). Moreover, Antonioli et al. (2011) show that greater economic performances are achieved by companies that adopt more than one type of innovation at the same time. These authors illustrate that the simultaneous adoption of different types of innovation, often process and organisational, can boost companies' economic performance as they tend to complement each other.

Overall the large branch of literature studying the relationship between technological innovation, change in skills and wages have clearly pointed out that there is a relationship between these factors, however it has some key weak points due to the fact that a macroeconomic perspective is missing. In particular should be necessary integrating these analyses taking in to consideration not only a narrow labour market perspective but also the socio-economic context in which the analysed changes take place.

3. Digitalisation and employment

The current section will focus on the more recent literature on the techno-economic features of digital economy and its impact on labour markets. We believe that the key findings of the large number of contributions that we presented in the previous chapter can be useful in understanding the impact of current digitalisation processes and their relationship with employment, as in many cases digital technologies offer new opportunities for product, process and organisational innovation. However, as we already pointed out in the introduction, digital technologies appear to have several disruptive uses and applications, offering radical new ways of manufacturing, buying and selling, organising, with important consequences on employment and on the functioning of the economic system more generally. For this reason in the current chapter we will first briefly recall the key features of the so called digital economy from a technological perspective, presenting the most relevant new technological opportunities, together with the debate on the effective possible uses and applications. Secondly, we will illustrate the contributions related to the impact of digital technologies on the economic system as a whole, as we believe is important to understand these transformations in order better recognise what the impact on employment may be. Finally, in section we illustrate the most relevant contributions on the employment implications of the current technological change.

3.1. Key features of digital economy

3.1.1. From a technological perspective

According to several authors (Brynjolfsson and McAfee, 2014; Rifkin, 2014), the current technological change offer some radical new opportunities that can lead to significant transformations not only in the way of producing and doing business but also in the overall economic system. In particular there is an increasing interest towards the impact of some specific technologies such as robots, the internet of things, the additive manufacturing, augmented reality, big data and analytics.

Among the others, the use of robots and their actual ability at substituting for human labour attracted most of the attention of literature contributions. The reason for that is that contemporary robots show the ability to substitute for labour not only in the low-skilled repetitive tasks but also in more complex high-skill occupations (for recent wide overview of robots and in particular on their use in social applications, see Royakkers and van Est, 2016). The ability of these robots is documented in particular by the case of the supercomputer Watson, developed by IBM, which competed and won against two humans in a famous American TV game show (Brynjolfsson and

McAfee, 2014). This episode demonstrated two relevant elements related to the cognitive ability of robots. On the one hand it showed that robots could do well in two abilities that according to Levy and Murnane (2004) only humans could succeed: "pattern recognition" and "complex communication".

In line with the observation of Polanyi (1966) that, as humans, "we know more than we can tell", Levy and Murnane suggested that computers could not fully replace human labour as computers are good at following rules but not at recognising a pattern. So, for example these authors point out that: "as the driver makes his left turn against traffic, he confronts a wall of images and sounds generated by oncoming cars, traffic lights, store fronts, billboards, trees, and a traffic policeman. Using knowledge, he must estimate the size and position of each of these objects and the likelihood that they pose a hazard [. . .] the truck drivers [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 task" (Levy and Murnane, 2004, p. 28). Moreover the same authors suggest that computers could not substitute for humans in complex communication: "Conversation critical to effective teaching, managing, selling, and many other occupations require the transfer and interpretation of a broad range of information. In these cases, the possibility of exchanging the information with a computer, rather than another human, is a long way off." (Levy and Murnane, 2004, p. 29)

According to Brynjolfsson and McAfee (2014), the case of Watson showed not only that computers could both dealing with pattern recognition and complex communication but also that they are very quick learners, as Watson did not win at the first tentative in 2006 but at the second one, four years later. Other authors questioned the actual possibility to fully overcome the Polany's paradox, sustaining that currently this has not happened yet as there are tasks that have proved to be very difficult to automate, in particular those involving "flexibility, judgement and common sense." (Autor, 2015, p. 22) According to this contribution, there may be "two distinct paths that engineering and computer science can seek to traverse to automate tasks for which we 'do not know the rules': environmental control and machine learning."

In relation to environmental control, by means of the case of the Google self-driving car, often pointed as one of the best example of the most sophisticated possibility to substitute for human skills, Autor (2015, p. 24) underlines that Google cars do not drive on roads but actually on maps: "a Google car navigates through the road network primarily by comparing its real-time audio-visual sensor data against painstakingly hand-curated maps that specify the exact locations of all roads, signals, signage, and obstacles. The Google car adapts in real time to obstacles, such as cars, pedestrians, and road hazards, by braking, turning, and stopping. But if the car's software determines that the environment in which it is operating differs from the environment that has been pre-processed by its human engineers—when it encounters an unexpected detour or a crossing guard instead of a traffic signal—the car requires its human operator to take control. [. . .] These examples highlight both the limitations of current technology to accomplish non-routine tasks, and the capacity of human ingenuity to surmount some of these obstacles by re-engineering the environment in which work tasks are performed."

Secondly, machine learning could overcome the problem that engineers are unable to program a machine to "simulate" non-routine tasks following a script procedure. In case computers are required to identify a chair, "relying on large databases of so-called "ground truth"—a vast set of curated examples of labelled objects—a machine learning algorithm attempts to infer what attributes of an object make it more or less likely to be designated a chair." Autor (2015, p. 25) However, according to the author, these tools, do not perform very well and if the famous computer Watson won in the TV show game, it is also true that it made also significant mistakes. Even if, according to Andreopoulos and Tsotsos (2013) these products should still be considered as prototypes as the underpinning technologies are all improving quickly, in Autor's view, when a person is required to identify a chair do so by knowing that the observed object is used to sit on. Therefore humans make use of the concept of "purposiveness", which is very difficult to automate and also difficult to be substituted by the recording of a large number of images.

Finally, we would like to recall one last controversial issue related to computers' abilities and the possibility for human labour substitution. While at the end of the 80s the cognitive abilities of computers were expanding thus opening up the possibility of substituting high skilled tasks the roboticist Hans Moravec (1988, p. 15) pointed out that it was "comparatively easy to make computers exhibit adult-level performance on intelligence tests or playing checkers, and difficult or impossible to give them the skills of a one-year-old when it come to perception and mobility." This point, later known as the Moravec paradox, was coherent with the cognitive scientist Steven Pinker (2007, pp. 190-91) when he suggested that "the main lesson of the thirty-five years of Artificial Intelligence research is that the hard problems are easy and the easy problems are hard [...]. As the new generation of intelligence devices appears, it will be the stock analyst and petrochemical engineers and parole board members who are in danger of being replaced by machines. The gardeners, receptionists, and cooks are secure in their jobs for decades to come." Even if currently there is no clear evidence that the so called Moravec paradox has been overcome, according to Brynjolfsson and McAfee (2014, p. 31), the collaborative robots Baxter, produced by Rethink Robotics, "are not as fast or fluid as a well-trained human worker at full speed, but they might not need to be" while have several advantages over human workers as "can work all day every day without needing sleep, lunch, or coffee breaks."

3.1.2. From an economic system perspective

As seen in the introduction, according to some scholars current technologies are so innovative that can lead to a new form of economic system. Although there is still no consensus on the founding principles of the digital economy, according to Valenduc and Vendramin (2016) there are five key elements that characterises the so called "digital economy".

The first characterising element is the role of digitalised information, which is a strategic economic resource in the new economic system. Already in the 90s some authors (Freeman and Soete, 1994; Castells, 1996) pointed out that there was a newly emerging economic system based on digitalised information and communication. In more recent time, the role of digitalised information became progressively clearer, according to Castells (2010) information is no longer an instrument to reduce transaction costs but can be seen as an abundant resource that can create value for the actors of both digital and traditional economy.

The second characteristic of the new economic system, according to Rifkin (2014) and Rochet and Volle (2015), is that digitalised goods and services are both intangible and non-rival and have zero or quasi zero marginal costs for reproduction. "One of the implications of the principle of growing returns is that the costs of production and distribution bear little or no relation to the volumes produced, but must be paid when the initial investment is made. The marginal cost of production is accordingly close to zero, and so although the digital economy is highly capital intensive, digital goods can be reproduced in vast quantities at zero or quasi-zero unit cost. Digital economy experts believe that markets for digitised goods and services follow a model of monopolistic or oligopolistic competition, hegemonised as they are by a few large companies which are frequently born of mergers and acquisitions and whose strategies boil down to locking in customers and keeping competitors at arm's length." (Valenduc and Vendramin, 2016, p. 10) If proven to be true, innovations delivering growing returns may represent a radical change as compared to the previous economic system, where innovation gains were very high only initially as they tended progressively to reduce with the diffusion of innovation (Rosenberg, 1994).

The third aspect characterising digital economy is the emergence of new business models. According to some contributions (Rochet and Tirole, 2006; Wauthy, 2008), these business models are favoured by the so called two-sided markets. Following to this theory, by means of online platforms there are two different groups that interact and benefit from the transactions. On one side there are consumers that have access to low-cost or free services, who in these contexts are also producers (sometimes called prosumers) as they supply the platforms with personal information. At the other side of the market there are economic actors that provide a service, benefitting from the fact that a large number of consumers make use of it, also because of the existence of positive externalities. According to Brynjolfsson and McAfee (2014) these platform-based business models modify the rules of competition as they are characterised by a "winner takes all" approach. In other words initially there is a competition between platforms for consolidating their position on the markets, but once the position is consolidated, thanks to the positive externalities linked to the progressive increasing member of users, the winner "takes all" and almost remains the unique provider.

The fourth pillar of the digital economy is the so called "Industry 4.0", which is term originating by the policy intervention put in place by the German Government since 2011. Under the umbrella of Industry 4.0 are generally included a number of emerging technologies that can be adopted in manufacturing and that we briefly recall here: robotisation, 3D printing, Internet of things (IoT), big data, Cloud computing, Augmented reality. Some of these applications, in particular robots, as we have seen in section 3.1.1, have drawn the attention of scholars because of the possibility of a new automatisation process. While we review later a part of the recent literature concerning the possibility of automating tasks and thus replacing jobs by means of new robots or computers, we anticipate that the impact of the other technological opportunities currently available have not been studied yet. For example, potentially manufacturing could be deeply transformed by an extensive use of 3D printing, as well as a large variety of possible product innovations may be available thanks to IoT but there are still no studies on the issue. The same can be said about the use of augmented reality or a more extensive use of big data analytics and cloud computing.

The last distinguishing feature of digital economy is related to the low costs of some of the new technologies, which could lead to an increase of profitability thanks to productivity gains. The existence of a direct link between innovation and productivity has been put into question by the Robert Solow in 1987 when he stated: "you can see computer age everywhere but in the productivity statistics." The casual link between technological innovation and productivity, as measured at macro level, has been discussed in the relevant literature and we recall here a number of factors that can explain the so called "Solow paradox". While at the micro-level the increase in productivity can be easier to be measured, it is more difficult to do the same at macro-level, in particular if productivity gains are achieved at the expenses of less innovative competitors. Moreover, the full absorption and exploitation of technological innovation takes time and it does not happen in the same way and with the same timings across different economic sectors.

In the following sections we present a review of the studies that have recently addressed the issue of the impact on employment of the current technological innovation. Most of the studies have selected some specific technological innovations and tried to measure the impact on employment, on the quantitative side, or understanding the most relevant changes in skills and in the forms of employment, on the qualitative one. Should be noted that not only with respect to Industry 4.0 there are no studies on the wide range of technological opportunities and their quantitative and qualitative impact on employment, but also macro level studies that take into consideration the transformations brought about digitalisation to the overall economic system are still missing.

3.2. The effects of digitalisation on employment

3.2.1. Quantitative and qualitative effects

In the last few years, a number of studies have been produced trying to estimate the employment effects of digitalisation processes. As pointed out before, the analyses produced so far are at micro or meso level, often focusing on the adoption of one specific technology for process innovation, rarely there are estimates based on the new business opportunities offered by technological change or studies that take into account macro level compensation mechanisms.

One of the most cited work was the realised by Frey and Osborne (2013) that estimates the probability of computerisation for more than 700 occupations in the US labour market. According to their results, about 47% of total US employment is at risk. According to their view "while computerisation has been historically confined to routine tasks involving explicit rule-based activities [. . .], algorithms for big data are now rapidly entering domains reliant upon pattern recognition and can readily substitute for labour in a wide range of non-routine cognitive. In addition, advanced robots are gaining enhanced senses and dexterity, allowing them to perform a broader scope of manual tasks [. . .]. This is likely to change the nature of work across industries and occupations." (Frey and Osborne, 2013, p. 44)

The same methodology has been applied for studies in Europe (Bowles, 2014), finding that the share of workers that may be displaced by technological change ranges between 40% and 60%. According to this study, the countries that will be affected most will be Romania, Portugal, Bulgaria and Greece.

A study on this issue was also produced by the World Economic Forum (2016), in this case using a survey of 370 companies around the world. The pool of respondents comprised the 100 largest global employers in each of the targeted industry sectors, overall the companies interviewed accounted for about 13.5 million employees.

As stated in the report, "respondents seem to take a negative view regarding the upcoming employment impact of artificial intelligence, although not on a scale that would lead to widespread societal upheaval—at least up until the year 2020. By contrast, further unpacking the bundle of technological drivers of change in the mould of the Fourth Industrial Revolution yields a rather more optimistic picture regarding the job creation potential of technologies such as Big Data analytics, mobile internet, the Internet of Things and robotics." (World Economic Forum, 2016, p.11) In terms of quantitative employment growth, "respondents expect strong employment growth across the Architecture and Engineering and Computer and Mathematical job families, a moderate decline in Manufacturing and Production roles and a significant decline in Office and Administrative roles. Other sizeable job families, such as Business and Financial Operations, Sales and Related and Construction and Extraction have a largely flat global employment outlook over the 2015–2020 period.' (World Economic Forum, 2016, p.11)

Other empirical results derived from a survey of 2.500 companies across European Countries are in line with the findings of World Economic Forum study: "the survey was less supportive of the view of some economists that structural change—globalisation and technological innovation in particular—is destroying jobs in Europe. According to the survey, the number of firms that are taking on more employees as a result of new technology is exactly the same as the number that are reducing their workforce for the same reason. And the number of firms that are expanding their workforce as they bring production in-house almost matches the number reducing their workforce as a result of outsourcing. There may be a lot of churn, but the net result is less than clear." (Dolphin, 2015, p. 15)

The study conducted by Frey and Osborne (2013) and other similar analyses that applied the same methodology have been criticised by different perspectives. In Valenduc and Vendramin's (2016, p. 16) opinion: "a failure to take account of the diverse nature of organisational change within companies and the complex nature of take-up processes for innovations is one of the main flaws" of the study, which "fell into all of the traps laid by the Solow paradox", that we recalled above.

According to Bessen (2015), who is also critical towards the Frey and Osborne's and similar studies, it is too simplistic thinking that just because computers can perform some tasks jobs will be eliminated. As an example of the opposite, he shows that during the 90s Automated teller machines (ATMs) diffused enormously, reaching more than 400,000 installed in the USA. Following the Frey and Osborne argument one should expect a strong reduction in the number of bank tellers, instead these have been constantly growing after 2000. In Bessen's analysis, this happened because banks increased the number of branches and because those tasks that could not be automated became more valuable: "as banks pushed to increase their market shares, tellers became an important part of the 'relationship banking team'. Many bank customers' needs cannot be handled by machines—particularly small business customers. Tellers who form a personal relationship with these customers can help sell them on high-margin financial services and products. The skills of the teller changed: cash handling became less important and human interaction more important."

In a recent contribution Autor (2015), recalling his previous works that distinguished between tasks and occupations as well as the work of Bessen discussed before, points out that there are several dynamics that need to be taken in to consideration when looking at the effects of technological innovation and employment, even in the light of the current technological opportunities. In Autor's view there are three factors that influence the impact of technological change on employment (Autor, 2015, p. 7): "First, workers are more likely to benefit directly from automation if they supply tasks that are complemented by automation, but not if they primarily (or exclusively) supply tasks that are substituted. A construction worker who is expert with a shovel but cannot drive an excavator will generally experience falling wages as automation advances. Similarly, a bank teller who can tally currency but cannot provide "relationship banking" is unlikely to fare well at a modern bank. Second, the elasticity of labour supply can mitigate wage gains. If the complementary tasks that construction workers or relationship bankers supply are abundantly available elsewhere in the economy, then it is plausible that a flood of new workers will temper any wage gains that would emanate from complementarities between automation and human labor input. [...] Third, the output elasticity of demand combined with income elasticity of demand can either dampen or amplify the gains from automation. In the case of agricultural products over the long run, spectacular productivity improvements have been accompanied by declines in the share of household income spent on food. In other cases, such as the health care sector, improvements in technology have led to ever-larger shares of income being spent on health."

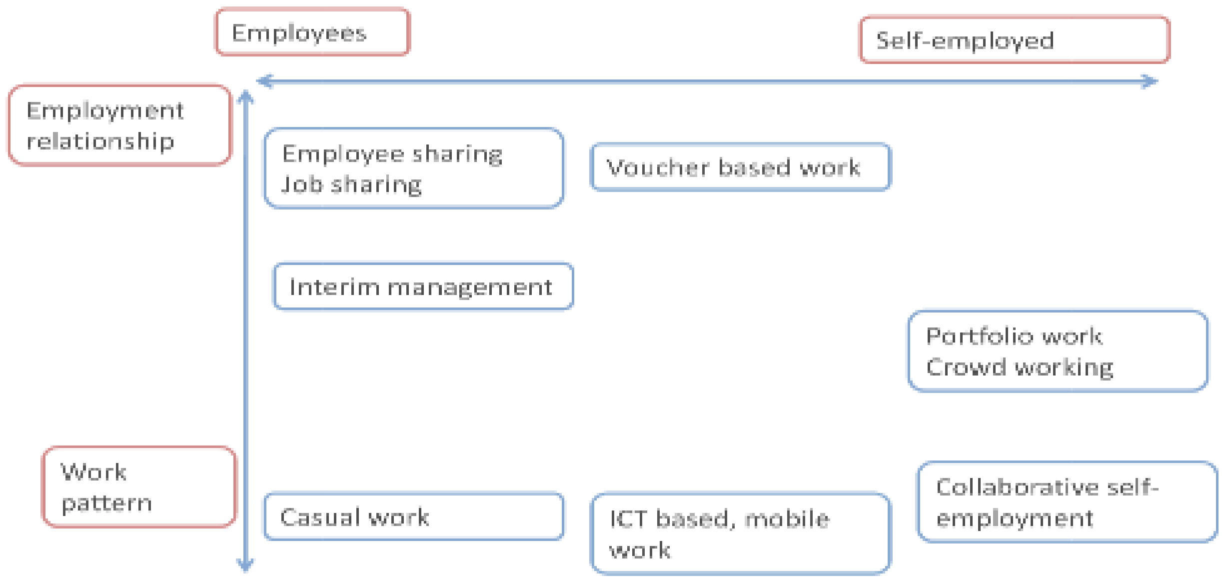
Other recent contributions (Graetz and Michaels, 2015; Acemoglu and Restrepo, 2017) have focused specifically on the effects of the use of industrial robots. Graetz and Michaels find that despite ubiquitous discussions of robots' potential impact, there is almost no systematic empirical evidence on their economic effects. By using data on a panel of industries in 17 countries from 1993-2007 the authors find that industrial robots increased labour productivity, total factor productivity, value added and wages. In relation to employment, robots had no significant effect on total hours worked, but according to the authors there is some evidence that they reduced the hours of both low-skilled and middle-skilled workers. To similar conclusions gets the work of Acemoglu and Restrepo (2017), which estimates the impact of the adoption of robots by American industry. They find that there is a negative and significant impact on employment and wages and most affected are low-skilled men, routine-manual jobs, but the aggregate impact of industrial robots remains small: from 1993 to 2007, US industries installed one additional robot per thousand workers and robots explain 0.65 percentage points of the decline in employment. However, according to their estimates, the future looks more problematic as US industries are expected to add 2.5 new robots per thousand workers causing a reduction of 1,75 percentage points of employment and a 4 percentage points of wages.

3.2.2. New challenges for the digitalised labour market

The debate about the effects of digitalisation on employment is not confined to the impact on the number of jobs and on skills, but there is a new branch of literature that is exploring new forms of employment. As we will see later in this section, some of these new forms of employment actually emerged already a few years ago, but the use of digital technologies helped expanding them. Other forms of employment are instead truly new, such in the case of platform labour, and are attracting the interests of scholars in particular in relation to the development of a new legal framework that could regulate these labour relations. According to Eurofound (2015), there are nine new forms of employment that can be plotted along two axes in the diagram in Figure 1. The horizontal axe relates to the nature of the relationship between employer and worker, in other cases between client and worker, the vertical exe instead relates to the way in which the work is performed (model of work).

Beginning with the forms of work located on top left area of the diagram, we find employee sharing and job sharing where in the first case an individual worker is jointly hired by a group of employer and works within different companies, in the second case a single employer hires more than one worker to perform one single job. Mowing down the diagram there is the so called "interim management", which is the case when a high skilled expert is employed on a temporary basis for a specific project. At the bottom left, casual work is even more flexible as there is a contract that allows employees to be called when they are needed, therefore without a regular work pattern. At the top centre there is voucher based work, where the employer pays a worker by means of a voucher issued by a third-party organisation such as a government body that covers pay and social contributions. In the case of ICT-based and mobile work workers do not have a fix location

Figure 1: New forms of employment



Source: Eurofound (2015)

for performing their activities but can work anywhere as a soon as they have internet connection. Crowd working is probably the most recent new forms of employment: by means of an online platform employers distribute mini work-tasks among a number of employees. Portfolio work is the case of a self-employed person carrying out several small jobs for different clients. Finally, collaborative self-employment is the case when a number of self-employees work together for the same project.

As anticipated before, among the different new forms of employment, it is probably crowd working the truly "new" form, which opens up the discussion related to the need of an adequate regulatory framework. Crowd working, together with work on-demand via apps is generally included under the term gig-economy (De Stefano, 2016; Smith and Leberstein, 2015; Sundarajan, 2016). As stated above, employers divide the job to be performed in micro-tasks that are then distributed to a large number of workers that can be located around the globe. In the case of crowd working tasks are often related to computer based work such as translations, work on images, data analyses etc. Differently, in case of the work on-demand via apps, the jobs are more traditional such as cleaning, transport and workers are called on purpose via mobile applications. Although these jobs are radically different, not only because crowd working requires more cognitive and knowledge skills while tasks in the app-work are more of manual type, but also because the in the first case the labour market is global, while in the second is primarily local, they share the fact that are not considered as work and therefore excluded by labour protection regulations.

Although crowdworking has been expanding in the last few years, little is known about it. According the findings of a survey conducted by ILO (Berg, 2016) among crowdworkers of Amazon Mechanical Turk and Crowdflower, crowdworkers are generally well-educated, and approximately half of them crowdwork for relatively long periods, like one year, a smaller percentage for even three years. In terms of reasons for crowdworking there were relevant differences between respondents located in advanced economies and those in developing countries. While workers in advanced economies crowdwork mainly to complement to the pay of other jobs, those placed in developing countries answered that they preferred or even could only working from home.

Both studies on the characteristics of non standard employment (NSE) in general and on gig-economy workers in particular are currently under development, with particular focus on the understanding of the phenomenon and the production of an adequate regulatory framework (ILO, 2016; De Stefano, 2016; Cherry and Aloisi, 2016; Rogers, 2016).

4. Conclusions and direction for further research

The present work aimed at providing a review of the main literature contributions related to the impact of digitalisation on employment. This issue has been attracting a growing interest, in particular because of the anxiety generated by the idea that digital technologies could cancel a large number of jobs. As we have illustrated in our work this fear has always been present in the past since the 19th century, in particular in those historical moments when machines showed the possibility of substituting for human labour, at least in some occupations or for some tasks.

For this reason we believe is important to recall the findings of this large empirical literature as in the current digital (r)evolution there are some radical new aspects affecting employment, but many phenomena share common trends with those seen in the past.

In particular, lot of attention is currently put on intelligent machines and more specifically on robots and on their (possible) ability to substitute for human labour. This technological advance is typically a process innovation that, as we have seen before, is proven to have a direct negative effect on employment, when studied at micro or meso level. However, macro level studies, although partially weak due to data unavailability and the complexity of the models, showed that there might be compensation mechanisms that could mitigate these effects. Moreover there is no consensus among scholars on the future effective capacity of robots to fully substitute for human labour, as there some skills such as flexibility, judgement and common sense or the ability to identify the purposiveness of objects that so far showed to belong exclusively to humans skills. If robots have received a great deal of attention so far, the impact on employment of other types of emerging technological opportunities such as for example 3D printing, Internet of Things, Augmented reality, Big data Analytics have not been studied yet. These new technologies offer opportunities not only for process innovation but also for significant product innovation, that a large number of studies proved to have positive employment effects.

Also in terms of the effects of technological change on skills, despite the extensive number of studies exploring the so called skill-biased-technical-change that illustrated the relationship between the polarisation of labour markets in terms of skills and wages and technological innovation, different trends are emerging that would require studies in the future. As pointed out by Acemoglu, differently from what emerged over the last forty years, "the experience of the nineteenth and early twentieth century led [. . .] to argue that technical change was 'deskilling'—a major purpose of technical change was to expand the division of labour and simplify tasks previously performed by artisans by breaking them into smaller, less skill-requiring pieces." If we consider some of the (few) known characteristics of crowdworking, a relevant new form of employment brought about digitalisation, it looks much more having nineteenth century characteristics rather than those of the late twentieth. This might cause, at least in this respect, a significant reversal in terms of skill demand.

Finally, in the present work we also illustrated that several literature contributions suggest that digital technologies can bring to a digital economy, with radical new business models and ways in which markets function. Even if research in this direction faces a level of complexity even higher than the one encountered by scholars studying the relationship between innovation and employment at macro-level, we believe that the significant changes to the overall economic system brought about by digitalisation need to be taken into consideration and explored when studying the impact on employment.

References

Acemoglu, D. (2002). Technical change, inequality and the labor market. *Journal of Economic Literature*, 40(1):pp. 7–72.

Acemoglu, D. and Autor, D. (2011). Skills, Tasks and Technologies: Implications for Employment and Earnings. In *Handbook of Labor economics*, chapter Vol. 4B, pp. 1043–1171.

Acemoglu, D. and Restrepo, P. (2017). Robots and Jobs: Evidence from US Labor Markets. *NBER Working Paper*, 23285, March.

Andreopoulos, A. and Tsotsos, J. (2013). 50 Years of Object Recognition: Directions Forward. *Computer Vision and Image Understanding*, 117(8):pp. 827–91.

Antonioli, D., Bianchi, A., Mazzanti, M., Montresor, S., and Pini, P. (2011). *Strategie di innovazione e risultati economici. Un'indagine sulle imprese manifatturiere dell'Emilia-Romagna*. Franco Angeli.

Autor, D. (2015). Why are there still so many jobs? The History and Future of Workplace Automation. *Journal of Economic perspectives*, 29(3):pp. 3–30.

Beaudry, P., Green, D., and Sand, B. (2016). The Great Reversal in the Demand for Skill and Cognitive Tasks. *Journal of Labor Economics*, 34(S1):pp. S199–S247.

Berg, J. (2016). Income security in the on-demand economy: Findings and policy lessons from a survey of crowdworkers. *Comparative Labour Law and Policy Journal*, 37(3):pp. 543–576.

Berman, E., Bound, J., and Machin, S. (1998). Implications of Skill-Biased Technological Change: International Evidence. *Quarterly Journal of Economics*, 113(4):pp. 1245–1279.

Bessen, J. (2015). Toil and Technology. *Finance & Development*, 52(1).

Bowles, J. (2014). *The computerisation of European jobs*. Bruegel Center, 17 July.

Boyer, R. (1988). Technical change and the Theory of Regulation. In Dosi, G., Freeman, C., Nelson, R., Silverberg, G., and Soete, L. (eds.), *Technical Change and Economic Theory*. London: Pinter.

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

Brynjolfsson, E. and McAfee, A. (2014). *The Second Machine Age: Work, Progress, and Prosperity in a Time of Brilliant Technologies*. WW Norton & Co.

Caroli, E. and Van Reenen, J. (2001). Skill biased organizational change? Evidence from a panel of British and French establishments. *Quarterly Journal of Economics*, 116:pp. 1449–1492.

Castells, M. (1996). *The rise of the network society*. Malden, Mass.: Blackwell Publishers.

Castells, M. (2010). *The rise of the network society*. Chichester: Wiley-Blackwell.

Chennells, L. and Van Reenen, J. (1999). Has Technology Hurt Less Skilled Workers? An Econometric Survey of the Effects of Technical Change on the Structure of Pay and Jobs. *London: Institute for Fiscal Studies working paper*, 27.

Cherry, M. and Aloisi, A. (2016). 'Dependent Contractors' in the Gig Economy: A Comparative Approach. *Saint Louis University Legal Studies Research Paper*, available at: `https://papers.ssrn.com/sol3/papers.cfm?abstract_id=2847869`.

De Stefano, V. (2016). The rise of the 'just-in-time workforce': On-demand work, crowdwork and labour protection in the 'gig-economy'. *ILO Conditions of Work and Employment Series Working*, 71.

Degryse, C. (2016). Digitalisation of the economy and its impats on labour markets. *ETUI Working Paper*, 2016.02.

Dolphin, T. (ed.) (2015). *Technology, globalisation and the future of work in Europe: Essays on employment in a digitised economy*. `http://www.ippr.org/publications/technology-globalisation-and-the-future-of-work-in-europe`: IPPR.

Doms, M., Dunne, T., and Trotske, K. (1997). Workers, wages and technology. *Quarterly Journa of Economics*, 112:pp. 253–289.

Dosi, G. (1982). Technological paradigms and technological trajectories: A suggested interpretation of the determinants and directions of technical change. *Research Policy*, 11(3):pp. 147–162.

Eurofound (2015). *New forms of employment*. Luxemburg: Publication Office of the European Union.

Freeman, C. and Soete, L. (1994). *Work for All or Mass Unemployment? Computerised Technical Change into the 21st Century*. London: Pinter.

Frey, C. and Osborne, M. (2013). The future of employment: how susceptible are jobs to computerisation? *Oxford Martin School Working paper*.

Graetz, G. and Michaels, G. (2015). Robots at work. *CEP Discussion Paper*, 1335(March).

Greenan, N. (2003). Organisational change, technology, employment and skills: An empirical study of French manufacturing. *Cambridge Journal of Economics*, 27(2):pp. 287–316.

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

Hall, B. (2003). Innovation and diffusion. *NBER Working paper series*, 10212.

Helpman, E. (ed.) (1998). *General Purpose Technologies and Economic Growth*. Cambridge, Mass: MIT Press.

Howell, D. (1996). Information technology, skill mismatch and the wage collapse: a perspective on the US experience. In *Employment and growth in the knowledge-based economy*. Paris: OECD.

ILO (2016). *Non-standard employment around the world. Understanding challenges, shaping prospects*. Geneva: ILO.

IPTS-EPSO (2001). *Impact of Technological and Structural Change on Employment. Prospective Analysis 2020, Synthesis Report and Analytical Report*. Seville: European Commission Joint Research Centre.

Krueger, A. (1993). How Computers Have Changed the Wage Structure: Evidence from Microdata, 1984-1989. *Quarterly Journal of Economics*, 108(1):pp. 33–60.

Leontief, W. and Duchin, F. (1986). *The Future Impact of Automation on Workers*. Oxford: Oxford University Press.

Levy, F. and Murnane, R. (2004). *The new division of Labor: How computers are creating the Next Job Market*. Princeton University Press.

Meyer-Kramer, F. (1992). The effects of new technologies on employment. *Economics of Innovation and New Technology*, 2:pp. 131–49.

Moravec, H. (1988). *Mind children: The future of Robot and Human Intelligence*. Cambridege, Mass.: Harvard University Press.

Perez, C. (1983). Structural change and the assimilation of new technologies in the economic and social system. *Futures*, 15(5):pp. 357–375.

Petit, P. (1995). Employment and Technological Change. In Stoneman, P. (ed.), *Handbook of the Economics of Innovation and Technological Change*, pp. 366–408. Amsterdam: North Holland.

Pianta, M. (2000). The Employment Impact of Product and Process Innovation. In Vivarelli, M. and Pianta, M. (eds.), *The Employment Impact of Innovation: Evidence and Policy*, pp. 77–95. London: Routledge.

Pianta, M. (2005). Innovation and Employment. In Fagerberg, J., Mowery, D., and Nelson, R. (eds.), *The Oxford Hand book of Innovation*, pp. 568–598. Oxford: Oxford University Press.

Pinker, S. (2007). *The language instinct*. New York: Harper Perennial Modern Classics.

Piva, M. and Vivarelli, M. (2002). The skill bias: comparative evidence and an econometric test. *International Review of Applied Economics*, 16(3):pp. 347–358.

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

Ricardo, D. (1951). Principles of Political Economy and Taxation. In Sraffa, P. (ed.), *The works and correspondence of David Ricardo*, chapter Vol. 1. Cambridge: Cambridge University Press.

Rifkin, J. (2014). *The zero marginal cost society, The internet of things, the collaborative commons, and the eclipse of capitalism*. Basingstoke: Palgrave MacMillan.

Rochet, J. and Tirole, J. (2006). Two-sided markets: a progress report. *The RAND Journal of Economics*, 37(3):pp. 645–667.

Rochet, V. and Volle, M. (eds.) (2015). *L'intelligence iconomique: l'iconomie et les nouveaux modèles d'affaires de la III révolution industrielle*. Louvain: De Boeck Université.

Rogers, B. (2016). *Redefining Employment for the Modern Economy*. October 2016, available at: `https://www.acslaw.org/sites/default/files/Redefining_Employment_for_the_Modern_Economy.pdf`: American Constitution Society for Law and Policy Issue Brief.

Rosenberg, N. (1994). *Exploring the black box. Technology, economics, and history*. Cambridge: Cambridge University Press.

Royakkers, L. and van Est, R. (2016). *Just ordinary Robots, Automation form War to Love*. Taylor and Francis Group.

Schumpeter, J. (1939). *Business Cycles*. New York: McGraw-Hill.

Simonetti, R., Taylor, K., and Vivarelli, M. (2000). Modelling the Employment Impact of Innovation: Do Compensation MechanismsWork? In Vivarelli, M. and Pianta, M. (eds.), *The Employment impact of Innovation*. London: Routledge.

Smith, R. and Leberstein, S. (2015). *Rights on Demand: Ensuring Workplace Standards and Worker Security In the On-Demand Economy*. New York: National Employment Law Project.

Solow, R. (1987). We'd better watch out. *The New York Times Book review*, 12th July.

Spiezia, V. and Vivarelli, M. (2002). Innovation and Employment: A Critical Survey. pp. 101–31.

Sundarajan, A. (2016). *The Sharing Economy. The End of Employment and the Rise of Crowd-Based Capitalism*. Cambridge, MT: MIT Press.

Tinbergen, J. (1974). Substitution of graduate by other labor. *Kyklos*, 27:pp. 217–226.

Tinbergen, J. (1975). *Income Difference: Recent Research*. Amsterdam: North-Holland Publishing Company.

Valenduc, G. and Vendramin, P. (2016). Work in the digital economy: sorting the old from the new. *ETUI Working Paper*, 2016.03.

Vivarelli, M. (1994). *Technology and Employment: The Economic Theory and the Empirical Evidence*. London.

Vivarelli, M. (1995). *The economics of Technology ans Employment: Theory and Empirical Evidence*. Aldreshot: Elgar.

Wauthy, X. (2008). Concurrence et régulation sur les marchés de plateforme: une introduction. *Reflets et Perspectives de la Vie Economique*, XLVII(1):pp. 39–54.

Whitley, J. and Wilson, R. (1982). Quantifying the Employment Effects of Micro-electronics. *Futures*, 14:pp. 486–495.

World Economic Forum (2016). The future of jobs—Employment, Skills and Workforce Strategy for the Fourth Industrial Revolution.