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The impact of Technological innovation on the Future of Work

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The Impact of Technological Innovation on the Future of Work

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Abstract

New digital technologies more and more diffuse into the economy. Due to this digitisation, machines become increasingly able to perform tasks that previously only humans could to. Production processes and organizations are changing, new products, services and business models emerge. These trends have important implications for European labour markets. This working paper presents up-to date evidence on the consequences of technological innovations on labour markets based on the academic literature and discusses the resulting policy challenges along with examples of policy responses. One key finding is that so far recent technological change has had little effect on the aggregate number of jobs but leads to significant restructuring of jobs. This implies three key challenges for European labour markets: first, digitisation induces shifts in skill requirements, and workers' fate in changing labour markets crucially depends on their ability to keep up with the change. Secondly, digitisation is not a purely technological process, but requires an accompanying process of organisational change. Thirdly, digitisation comes along with rising shares of alternative work arrangements, due to more outsourcing, standardisation, fragmentation, and online platforms. These alternative work arrangements imply both new opportunities and challenges. These challenges require adequate policy responses at the European, national and regional level, which the working paper outlines for education and training policies, active labour market policies, income policies, tax systems and technology policies.

Keywords: Technical Change, Structural Change, Labour Markets, Europe

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Introduction

Labour markets are constantly evolving as new technologies alter the "division of labour" between humans and machines. In particular, technological change affects the demand for and supply of labour and thereby has important consequences for individuals and businesses, employment, wages and workplace organization. This calls for tailored labour market institutions and policies. With the advent of new digital technologies since 2000 and the most recent advances in robotics and artificial intelligence, understanding the evolution of the labour market in response to this ongoing Digital Revolution is important for businesses and policymakers. By the Digital Revolution, we refer to the accelerating application of digital technologies in production and organisational processes or to create new products, services, or business models. We will use the terms Digital Revolution, technological innovation/change and digitalisation interchangeably for this trend.

Drawing on the most recent academic literature[1] this paper provides an overview of the impact of digitalisation on employment levels, structure and wages and discusses related policy challenges. Based on this, we will discuss potential consequences of the upcoming change and potential policy options. In addition, we will touch upon non-standard forms of employment that have been on the rise, in particular platform work. As these new forms of work still comprise only a marginal share of the economy, the main focus will be on standard forms of employment. Moreover, while the Digital Revolution is one of the main labour market trends, labour markets are also affected by parallel trends such as globalisation and demographic ageing. These trends likely interact with each other, but we do not elaborate on these interactions here and refer to Autor et al. (2016) and Harrison et al. (2011) for overviews on the labour market consequences of globalisation, or to Clark et al. (2006) for the consequences of demographic ageing.

The remainder of this paper is structured as follows. The first section provides the general backdrop to the paper and how it contributes to our knowledge by combining recent insights from the literature. The paper then describes the impact of the Digital Revolution on the number of jobs, the structure of jobs, and the changing nature of jobs, and gives an outlook on the potential challenges of upcoming technologies. The final section identifies the main policy areas where challenges from technological progress arise and discusses specific policy instruments at EU and national level that aim to address these challenges.

The impact of the digital revolution on labour markets

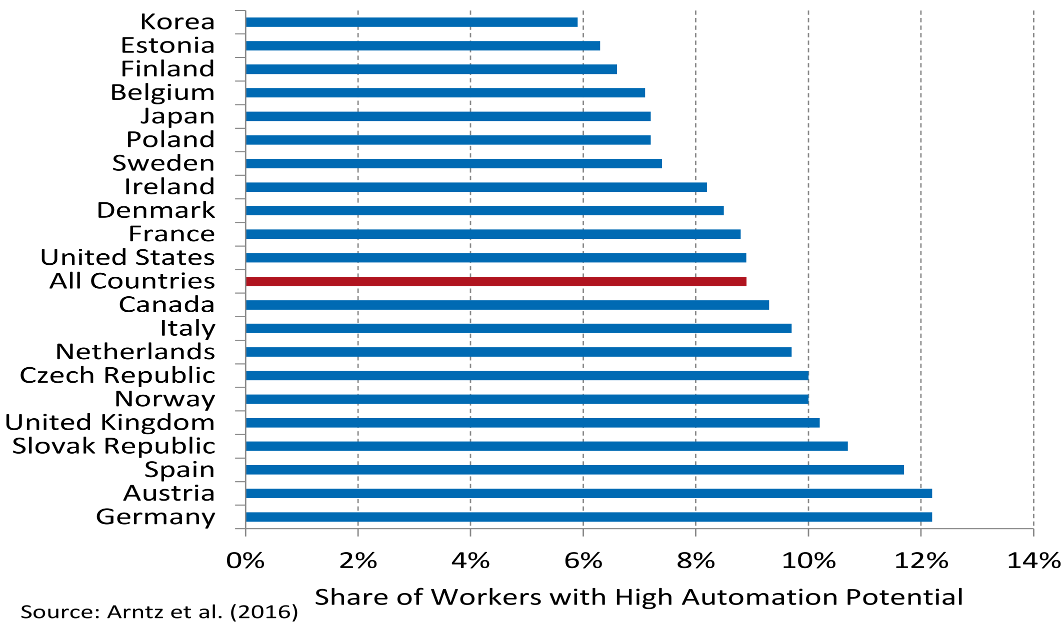
In this section, we will discuss the effects of the digital revolution on labour markets. We start by presenting a general framework of how to think about technologies' impact on labour markets. Based on the framework, we then discuss the impact that the digital revolution has had so far on the number of jobs, on their structure and on their nature. We will then give an outlook on how upcoming digital technologies might affect the labour market in the near future.

[1] There exists a large and growing grey literature on the potential effects of digitalisation. Within the scope of this paper, however, we will rely on scientific evidence from the academic literature where possible.

The digital revolution: A General Framework

Popular fears that upcoming technologies may make labour redundant in an increasing number of occupations have been fuelled recently by studies which claim that up to half of U.S. jobs are automatable within the next two decades. For example, Frey and Osborne (2016) claim that 47% of U.S. workers are “at risk”, meaning that the typical tasks of those jobs could likely be done by new machines. However, as Arntz et al. (2017) have shown, such occupation-level studies severely overestimate automation potentials, because they neglect that workers already adjust their tasks to new technologies at the job level. They show that the share of U.S.-workers with high automation potentials declines to 9% when taking into account the variation of tasks within occupations across jobs. This has been confirmed by a recent study from Nedelkosta and Quintini (2018). Arntz et al. (2016b) report comparable figures for other OECD countries, ranging from 6% in Korea to 12% in Germany and Austria (see Figure 1).

Figure 1: Automation Potentials in OECD Countries



Source: Arntz et al. (2016)

Although these studies differ quantitatively, a common theme is that they focus on the feasibility of automating worker tasks. This susceptibility of tasks to automation is in contrast to the prevailing presumptions in much of macroeconomics and labour economics. Until recently, technological progress was believed to increase the productivity and therefore labour demand of both unskilled and, even more so, skilled workers. Consequently, wages and employment would increase for both unskilled and skilled workers (Katz and Murphy 1992). Although wages of skilled workers have increased indeed, Acemoglu and Autor (2011) show that wages for unskilled workers started to decrease instead of increasing in the 1980s. The susceptibility of worker tasks to automation discussed above also implies that some workers (and not necessarily only those that are low-skilled) might see their labour demand decrease following technological progress. In sum, conventional wisdom about the impact of ongoing technological progress on labour markets falls short of explaining several recent empirical phenomena.

In reaction to these puzzles, a new framework to think about the impact of ongoing technological progress on labour markets has recently emerged in the literature (Autor, Levy Murnane 2003;

Goos, Manning and Salomons 2014; Acemoglu and Autor 2011; Acemoglu and Restrepo 2017, 2018). This framework, rather than assuming that technological innovations augment the productivity of all types of workers, explicitly addresses the possibility that innovation can directly displace some workers from their tasks, thereby decreasing the demand for their labour. This new framework also accounts for various adjustment mechanisms that can act as countervailing forces which increase labour demand. These various adjustment mechanisms have recently been integrated into a single framework by the seminal contribution of Acemoglu and Restrepo (2018, AR hereafter). In this paper, we rely on the comprehensive framework by AR in order to discuss how digitalisation affects labour markets. Their framework covers four main mechanisms:

- *Displacement effect*: as machines become increasingly able to perform tasks that previously only humans could do, firms will more and more apply those technologies to substitute for human labour. This reduces the demand for labour.
- *Productivity effect*: the substitution of labour by cheaper machines reduces production costs, which induces declining prices and expanding demand and production. Moreover, new technologies may raise the quality of products or enable new products and services, raising demand and production if consumers value the rise of quality or the new products and services. This expansion of the economy raises demand for labour.
- *Capital accumulation effect*: the adoption of new technologies implies rising demand for new machines and intangible capital, which increases the demand for knowledge-based tasks and for labour tasks that involve producing, implementing, maintaining and upgrading the new technologies in use. This raises demand for labour.
- *Reinstatement effect*: new technologies induce the creation of new tasks for workers for two reasons: Firstly, the displacement of workers from old tasks implies that more workers are available to take over new, more productive tasks. Secondly, new machines and the rise in knowledge-based capital may directly require new tasks (e.g. machine operation) or enable new tasks (e.g. platform work). The creation of new tasks directly counteracts the displacement effect by raising demand for labour.

In sum, whereas new technologies are likely to displace some workers from their tasks, they will necessarily change the jobs of those workers who remain. Whether digitalisation leads to an increase or decrease of employment, ultimately depends on the relative sizes of the *displacement effect* and the compensating effects *(productivity effect, capital accumulation effect and reinstatement effect)*. In the remainder of this paper, we argue that an understanding of the nature and magnitude of each of these channels of adjustment is central for workers, businesses and policy makers.

Total employment effects

As machines become increasingly able to perform tasks that previously only humans could do, fears are rising that technological change might displace large numbers of workers from their jobs. These fears have accompanied previous phases of technological change, but long-lasting technology-induced unemployment has not occurred so far despite large automation potentials (Mokyr et al. 2015, Autor 2015). Automation potentials do not necessarily lead to net employment losses. Rather, employment effects depend on the interaction between several macroeconomic adjustment mechanisms, as highlighted by the AR framework outlined above.

Whether the counteracting effects *(productivity effect, capital accumulation effect and reinstatement effect)* are sufficient to offset or even overcompensate the displacement effect is, ultimately, an empirical question. Employment effects of new technologies have been studied frequently at different levels. In this section, we will survey empirical results on the total employment effects of technological innovations to discuss whether the net aggregate employment effects have been positive or negative in the recent past. These studies can be roughly categorised into firm-, sector- and regional-level studies.

Firm-level studies often report that innovative firms, which adopt new technologies, grow faster and create more jobs. In particular product innovations are associated with higher employment growth, which for example has been documented for Germany, Austria and Britain. This suggests that the *productivity effects* overcompensated the *displacement effects*. The results for process innovations are less clear, although they often are positive but insignificant (Chennells and van Reenen 1999; Pianta 2009; Vivarelli 2007). Existing evidence on the specific effects of ICT adoption and use on firms' employment in the EU does not support the hypothesis that digitalisation has reduced employment (Pantea et al., 2017; Biagi and Falk, 2017). However, it has changed its composition, favouring highly skilled workers (Falk and Biagi 2017). Whether this is a causal effect often remains unclear, as e.g. fast-growing firms invest more into new technologies. In addition, firm-level results cannot be transferred to aggregate employment effects, as positive employment effects in innovative firms could be offset by employment losses in competing firms.

Sector-level studies take into account this reallocation of workers between less and more innovative firms. There exists a large literature on the employment effects of innovations and new technologies, particularly for Western economies. This literature reports quite heterogeneous results, as e.g. surveyed by Feldman (2013), Pianta (2009) or Vivarelli (2007). A drawback of many studies, mostly older ones, is that they often either do not rely on explicit identification strategies or that they impose strong assumptions for identification. Hence, it often remains unclear whether the relationship between innovation, technological change, and employment growth can be interpreted in a causal way. The OECD (2016b) looks at the impact of ICT investments on labour demand and finds the long-run aggregate effects to be neutral, indicating that the negative displacement effects are compensated by positive counteracting effects. However, it also finds that ICT investment tends to favour employment growth for highly skilled individuals.

As for robotisation and employment, a recent study by Graetz and Michaels (2015) for 17 OECD countries[2] shows that the additional use of robots between 1993 and 2007 raised both labour productivity and value added at the sectoral level by about 0.36 and 0.37 percentage points, respectively, as suggested by the *productivity effect*. At the same time, they find no significant effects on total hours worked, although they report negative effects for low-skilled workers. Hence, *displacement effects* seem to be larger for low- and medium-skilled workers, while on average the *displacement effect* seems to be more or less offset by *productivity effects*. Sectoral-level studies tend not to explain the effect of innovations on the whole economy as they typically do not take into account reallocation from innovative- to non-innovative sectors.

Other studies rely on regions as small economies to study economy-wide effects of technological change. Dauth et al. (2017) find neutral net effects of robots in German local labour markets between 1994 and 2014. This is accompanied by a loss of about 2.12 jobs in manufacturing per additional robot, which is fully compensated by rising service employment. Hence, local labour markets with a higher exposure to robots did not experience net employment losses. Acemoglu and Restrepo (2017), to the contrary, document negative overall effects of robots in US local labour markets between 1993 and 2007. According to them, an additional robot reduced total employment by about 6.2 workers in an average local labour market. Hence, *productivity, reinstatement and*

[2] Australia, Austria, Belgium, Denmark, Finland, France, Germany, Greece, Hungary, Ireland, Italy, Netherlands, South Korea, Spain, Sweden, United Kingdom, United States.

capital accumulation effects of robots apparently are strong enough to compensate their *displacement effects* in Germany, but not in the US. They also highlight that the employment effects of robots seem to strongly differ from that of computerisation more broadly. Indeed, Gregory et al. (2016) document that capital-labour substitution due to computerisation, in general reduced labour demand between 1999 and 2010 by 9.6 million jobs across Europe *(displacement effect)*, but that this was overcompensated by induced *productivity* effects. They report a net positive labour demand effect of computerisation by 11.6 million jobs, which correspond to roughly half of the overall increase in employment during that period. Autor and Dorn (2013) indicate no net negative employment effects of computerisation in the US. In a study for 6 EU member states Chiacchio, Petropoulou and Pichler (2018) find that one additional robot per thousand workers reduces the employment rate by 0.16-0.20 percentage points, meaning that a significant displacement effect dominates.

One reason for the heterogeneity of the employment effects of new technologies and innovations is that the effects depend on the market environment and institutional setting. For example, in an environment of stagnating demand, process innovations tend to reduce employment (Feldmann 2013, Pianta 2009, Vivarelli 2007). If competition is low, firms may not pass on cost declines to consumers, in which case the productivity effect may be too small to compensate the displacement effect (Vivarelli 1995, Tancioni and Simonetti 2002). Moreover, the compensating effects might be too small if the labour market is not sufficiently flexible and the capital accumulation effect is typically larger in technologically leading countries which produce those technologies (Simonetti et al. 2000). As highlighted above, technological change in the past did not lead to long-lasting increases in unemployment (Autor 2015), and the existing findings for the recent impact of computerisation also do not point towards net employment losses, although the results for specific technologies such as robots are less clear.

Evidence from past phases of rapid technological change thus, at first glance, seems to be conflicting. However, a closer look reveals that differences in the results can be related to differences in identification strategies, with many studies reporting correlations rather than causal effects. Differences also relate to analyses at different levels, with firm- and sector-level studies neglecting adjustment processes between firms or sectors. Moreover, studies differ in the scope of the technologies that they address – for example, some focus on very specific technologies (e.g. robots), whereas others address digitalisation or automation more broadly. A general result from the existing literature is that technological change does not lead to significant negative, but instead mostly even to positive effects on net aggregate employment once adjustment processes between firms and sectors have been taken into account.[3]

Whether future technologies will reduce or actually raise employment remains to be seen. Scenarios on future impacts of new technologies often confirm small net but large structural effects. For example, a scenario for the German economy suggests large technology-induced structural shifts in employment, but hardly any change in the level of employment (Wolter et al. 2016).[4] Given the uncertainty of such scenarios, the predicted decline in employment of 5.1 million jobs across 15 major countries by the World Economic Forum (2016) is negligible, as this represents less than 0.3% of employment in those countries (1.86 billion).

[3] Note that most empirical studies rely on reduced-form approaches. Thus, they implicitly take into account the different adjustment mechanisms of the Acemoglu and Restrepo (2018) framework, although they cannot separately identify the contributions of the different mechanisms without further analysis.

[4] Wolter et al. (2016) report a technology-induced decline of employment in Germany by 30.000 jobs until 2030, which corresponds to less than 0.1% of all employees in Germany. Given the long time period and the uncertainty of such scenarios, the size of the effect is minuscule.

Structural effects and inequality

Changes in relative wages and employment

While the net employment effect of technological change is often small because direct *displacement effects* are being outweighed by compensating mechanisms *(productivity effect, capital accumulation effect, reinstatement effect)* working through labour and product markets, this is typically accompanied by huge restructuring.

A main finding from the early literature is that technological change during the 1970s and 1980s was mostly skill-biased, leading to rising relative demand for high-skilled workers. As the rising demand for high skilled workers was accompanied by a rapid expansion of educational attainment, the wage premium of high-skilled relative to low-skilled workers initially did not rise. Only when the educational expansion slowed down at the beginning of the 1980s, also wages of high-skilled workers began to rapidly rise relative to low-skilled workers. This has been documented for the US (Murphy and Welch 1992; Katz and Murphy 1992; Blackburn et al. 1989; Acemoglu and Autor 2011) and in several OECD countries (Australia, Canada, Denmark, France, Germany, Italy, Japan, the Netherlands, South Korea, Sweden, and the UK), although the rise in relative wages for high-skilled workers is usually observed only in Anglo-Saxon countries and less in continental Europe (Machin and van Reenen 1998, Freeman and Katz 1994). In Germany, rising wage inequality is reported only with a lag of about one decade compared to the US (Dustmann et al. 2009; Antonczyk et al. 2010). Several studies indicate that technological change was indeed one major cause of rising relative demand for high-skilled workers (c.f. Bound and Johnson 1992; Katz and Murphy 1992; Freeman and Katz 1994; Berman et al. 1994; Machin and Van Reenen 1998; Lawrence and Slaughter 1993; Berndt et al. 1992; Autor et al. 1998; Machin 1996; Haskel und Heden 1999).

Starting with computerisation, which began in the late 1980s, this pattern changed. Computerisation substituted for routine tasks, implying larger *displacement effects* for those workers, whereas *productivity and reinstatement effects* are larger for non-routine workers. This induced workers to shift to either manual or cognitive tasks in Germany (Spitz-Oener 2006), Japan (Ikenega and Kambayashi 2010), Sweden (Adermon and Gustavsson 2011), the UK (Goos and Manning 2007), the US (Autor et al. 2003; Autor et al. 2006), and in other European Countries[5] (Goos et al. 2009, 2014; Oesch and Rodríguez Menés 2011). As the declining routine tasks are wide-spread among middle-paid occupations, this was accompanied by a shrinking middle of the wage distribution and growing poles (high and low wage occupations). This polarisation of employment has been documented in many Western economies for the 1990s (Goos and Manning 2007, Autor et al. 2006, Ikenega and Kambayashi 2010, Adermon and Gustavsson 2011, Goos et al. 2009, 2014, Oesch and Rodríguez Menés 2011, Senftleben-König and Wieland 2014, Kampelmann and Rycx 2011).

In addition to employment polarisation, in some cases there also is wage polarisation, i.e. faster wage growth at the poles of the wage distribution compared to the middle (Autor 2013, Acemoglu and Autor 2011) in the US (Autor et al. 2008; Autor and Dorn 2013; Firpo et al. 2011) and in some OECD countries (Atkinson 2008). In Germany, the wage distribution instead became more unequal

[5] Goos et al. (2009, 2014) study Austria, Belgium, Denmark, Finland, France, Germany, Greece, Ireland, Italy, Luxembourg, the Netherlands, Norway, Portugal, Spain, Sweden, and the United Kingdom. Oesch and Rodríguez Menés (2011) study Britain, Germany, Spain and Switzerland.

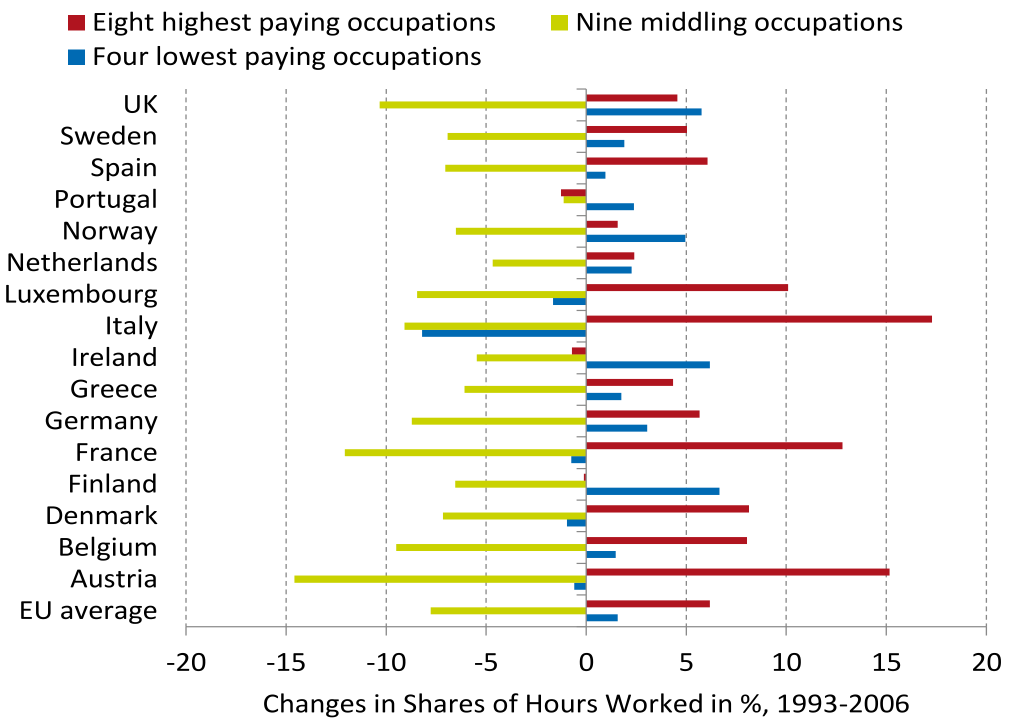
throughout the 1980s and 1990s (Dustmann et al 2009; Antonczyk et al. 2010; Kampelmann and Rycx 2011; Senftleben-König and Wieland 2014).

In Europe, employment polarisation has also been the dominant pattern of employment restructuring, but pronounced differences can be found across countries (Goos et al. 2009; Oesch and Rodríguez Menés 2011). In particular, the shrinking employment share of occupations in the middle of the wage distribution in 16 EU countries has only been accompanied by increasing employment shares at both poles of the distribution in Germany, Greece, the Netherlands, Norway, Spain, Sweden and the UK (see Figure 2). These varying patterns of restructuring across countries, but also regions and sectors seem to be linked mainly to the exposure to technological change, i.e. the share of routine jobs that are vulnerable to capital-labour substitution (Autor and Dorn 2013, Goos et al. 2009). Moreover, whereas employment growth in high-paid occupations takes place in almost all countries, the expansion of low-paid jobs is not as uniform across countries. Goos et al (2014) show that the demand for mid-paid jobs decreases in comparison to high-paid and low-paid occupations because, first of all, current technological change is biased towards replacing labour in routine tasks and, second, there is a phenomenon of task offshoring. This is partly mitigated by labour supply up-skilling.

Eurofound's European Jobs Monitor (2014) shows a significant diversity of patterns of structural employment change in Europe. Fernández Macías (2015) argues that most of the diversity across countries and periods relates to middle and low-paid occupations (period 1995-2013). This variety of patterns across countries likely reflects that country-specific institutions and policies mediate the labour-market consequences of technological change (Fernández Macías 2012, Fernández Macías and Hurley 2016, Hurley, Fernández Macías and Storrie 2013, Oesch and Rodríguez Menés 2011, Oesch 2013, Tahlin 2007). Powerful unions, heavy pay-roll taxes, high minimum wages and generous unemployment benefits compress the wage structure and may hamper the creation of a low-wage sector. Hence, the growth of the low-wage sector was stronger in countries where this sector is relatively unsheltered from market pressure, such as the UK, and less strong in countries with a more compressed wage distribution such as Germany, Spain or Switzerland (Oesch and Rodríguez Menés 2011). However, employment started polarising in Germany, as wage compression declined strongly since the Millennium. This is likely linked to both, the "Hartz" labour market reforms and the declining union power due to offshoring after the fall of the Iron Curtain (Dustmann et al. 2014). This supports the view that institutions mediate the effects of technological change on the labour market.

Educational institutions also potentially affect the consequences of technological change. For example, Rendall and Weiss (2016) argue that polarisation in Germany was slower due to the apprenticeship system, as the incentives for firms to substitute these skilled workers are lower compared to countries with less formal training. Finally, the effects of technological change potentially also vary within countries. For example, Dauth (2014) shows that job polarisation in Germany almost exclusively occurs in urban areas and that export-oriented regions face stronger polarisation.

Figure 2: Employment Polarisation in European Countries



Source: Goos et al. 2009, Table 2.

While the above results refer to long-term trends on the labour market, a key question is which skills will be required on future labour markets. Recently, there has been a slow-down in the rise of the wage premium for high-skilled workers (Autor 2014, Beaudry et al. 2015). This may be either due to a deceleration of the increase in relative demand for those workers, or due to an increase of their relative supply. Beaudry et al. (2015) find that since the year 2000, high-skilled workers went down the occupational ladder, replacing middle-skilled workers in their lower-paid jobs. They argue that this is due to a decline in relative demand for high-skilled workers after a peak during the phase of large investments into ICT technologies. Hence, they argue that the *productivity* and *reinstatement effects* of technological change were particularly large during the investment phase, and that they became smaller thereafter. Autor (2014), instead, highlights the role of the fast rise in high-skilled education for the flattening out of the skill-wage premium. Nevertheless, high-skilled workers continue to earn substantially more. Whether this remains true in the near future is unclear. Studies on automation potentials mostly suggest that jobs which require high levels of education are typically less exposed to job automation, even though machines become increasingly able to also perform high-skilled tasks (Arntz et al. 2016b).

Firm- and worker-level consequences

Thus, technological change induces a strong structural change, even if its aggregate net employment effects typically remain small at the national level. This restructuring of jobs between tasks, occupations and sectors may severely challenge highly exposed workers and depress their labour market prospects. The *displacement effect* induced de-routinisation and occupational downgrading from middle-paid routine to low-paid service jobs (Autor and Dorn 2013, Cortes et al. 2017). In addition, wages of workers who remained in their routine jobs fell. Their wage growth was lower by 5-12% over 10 years compared to those who switched to non-routine manual jobs. (Cortes

2016). Only high-ability workers were able to switch to higher-paid cognitive jobs. Their wage growth was higher by 14-16% over a 10-year period compared to those who stayed in routine occupations (Cortes 2016). Hence, the fate of workers during technological turmoil depends on their ability to switch towards expanding tasks and occupations.

Autor and Dorn (2009) find that particularly old workers often fail to occupationally upgrade and instead downgrade from middle-paid routine to low-paid service jobs. Only young workers exhibit both downward and upward occupational mobility. In addition, upward mobility is strongly linked to educational attainment – it is mostly highly educated young workers who manage to upgrade to high-wage non-routine occupations, whereas less educated and older workers are more likely to downgrade.

Nevertheless, occupational restructuring due to technological change does not necessarily imply that workers have to switch from routine to non-routine occupations. Instead, occupational restructuring may occur by changing compositions of new entrants. In fact, Dauth et al. (2017) find that the introduction of robots did not increase the displacement risk of incumbent manufacturing workers, but actually raised job stability. Employment among manufacturing workers instead declined via fewer new entrants, as new entrants were increasingly employed in service jobs. Despite stable careers, workers in routine occupations face declining earnings, not because of career interruptions, but because of lower wages. These results are confirmed by Cortes et al. (2016), who find that the declining share of routine occupations is mostly explained by fewer unemployed and non-participants entering routine occupations. The *displacement effect*, highlighted by the AR framework, thus not necessarily implies job separations, but may instead imply fewer vacancies.

The polarisation of occupational structures is also accompanied by rising firm specialisation, as highlighted by Cortes and Salvatori (2018). The authors document that the increase of non-routine employment share is mostly explained by workplaces specialising in non-routine tasks. Non-routine workers increasingly concentrate in workplaces that specialise in non-routine tasks. Quite interestingly, these changes occur mostly within industries and among establishments with similar characteristics. Hence, a large part of polarisation is occurring between firms, as firms more and more specialise in certain tasks. A potential explanation for this finding is that technological progress induces firms to specialise on their core (non-routine) tasks and to outsource routine cognitive tasks.

New technologies and globalisation potentially further raise the relative advantage of the most productive firms in each industry. Examples, such as Google, Facebook or Amazon are well-known. Digitalisation enables such firms to capture huge economies of scale via network effects or big data. This is often described as “winner-take-all” markets. Indeed, Autor et al. (2017) document rising importance of such “superstar firms” in the U.S. This rise induces a fall of the labour share in national income, as superstar firms make huge profits but have low shares of labour in firm value-added (Autor et al. 2017). In addition, within-firm wage inequality rises in the largest firms of the U.S. due to substantially rising wages at the very top positions and falling wages at the bottom half of the within-firm wage distribution. Nevertheless, the wage-premium of large firms shrank, which mitigated the general increase in wage inequality (Bloom et al. 2018; Song et al. 2016).

Technological Change and the Future of Work

Technological change not only affects the aggregate number and structure of jobs, but also comes along with organisational changes and corresponding shifts in skill demands. Moreover, new forms of work are evolving in the course of technological innovations and changing worker preferences. In the following section, we briefly review the current literature on these issues in light of the AR framework.

Skill requirements

As discussed in section 0, current technological advances are likely to have a strong impact on the creation and destruction of jobs and workplaces, thereby shifting the demand for skills. In addition, the adoption of new technologies is likely to also affect the task content and related skill requirements of existing occupations and workplaces. In fact, much of the adjustment to changing skill demands seems to take place within rather than between occupations (Spitz-Oener 2006). Clearly, occupations such as secretaries or car mechanics have undergone dramatic changes across time in terms of the skills and competencies needed but have not vanished from the labour market. Understanding the nature of the changing skill requirements in the course of the digital transformation is important as such changes need to be addressed adequately by educational policies in order to close skill gaps and thereby ensure the employability of workers.

As a very basic insight from the recent literature, machines mainly seem to be capable of substituting for tasks *(displacement effect)* that can be codified easily and follow certain routines such as exchanging information, selling or manual tasks. Machines, instead, tend to complement tasks *(productivity and reinstatement effect)* that need non-routine analytical and interactive skills such as abstract thinking, creative work, problem-solving and negotiating (Arntz et al. 2017, Frey and Osborne, 2016, Martin, 2018). Supplementing this evidence, a recent study suggests that the general cognitive capabilities of a third of all workers in 2016 and up to two thirds of all workers in 2026 are or will be below the level of proficiency reached by computers (Elliott 2017).[6] According to the capability approach to recent technological change, machines are thus mainly complementary to high-skilled workers while the share of tasks that can potentially be substituted by machines tends to increase the lower the skill level.

However, evidence on the employment and wage prospects of workers with a higher education indicates that the complementarity of technological advances and skills may have become more complex. While until the early 2000s the rising returns to tertiary education indicated a complementary nature of machines and cognitive skills (Katz and Murphy 1992, Acemoglu and Autor 2011), the wage returns to formal education and cognitive skills have decreased during the last decade compared to the 1980s (Castex and Dechter 2014) and employment growth in high-paid, cognitive skill-intensive jobs has stagnated recently in the US (Acemoglu and Autor 2011, Beaudry et al. 2015). For Germany, Reinhold and Thomsen (2015) find evidence that job entrants with a higher education are increasingly less likely to end up in analytical graduate jobs and that the wage premium for workers with a tertiary education increased until 2002 but stagnated thereafter. Among typical graduate occupations, Deming (2017) shows that jobs in science, technology, engineering and mathematics[7] experienced a relative wage decline in the last decade while occupations that combine cognitive skills with a significant share of interactive tasks such as, for example, managers and teachers all experienced a marked growth. This is consistent with Altonji et al. (2014) who show that only until the early 2000s there has been a strong increase in the returns to college majors that typically work in abstract-intensive occupations while the returns to these majors declined afterwards. Moreover, returns to higher education became more dispersed

[6] The study compares the literacy, numeracy and digital problem-solving scores as reported for OECD workers in the PIACC data to computer capabilities assessed by computer experts.

[7] With the exception of computer scientists and programmers.

across college majors, but also due to increasing returns to unobservable abilities and match-specific characteristics (Altonji et al. 2014, Green and Henseke 2016). In line with this, Card et al. (2013, 2015) find that the heterogeneity in worker-specific wage premiums has increased since 2000, also pointing to an increasing return to unobservable individual-specific characteristics.

Hence, although recent technological advances continue to be biased towards cognitive skills such that rising numbers of college graduates during the last decade still face quite stable albeit no increasing returns to their education, labour market prospects seem to increasingly hinge on the possession of skills beyond formal education. In fact, Bode et al (2016) suggest that digitalisation might actually be biased not only with respect to cognitive skills that are typically obtained by education but also with respect to personality traits. In particular, they find that even after controlling for educational attainment, workers with better personality traits are less prone to being replaced by new digital technologies. In support of this, Deming (2017) shows that the share of jobs that require a high level of social interaction increased by 12 percentage points in the US between 1980 and 2012 and that the returns to social skills have been increasing strongly in the same period. Interestingly, he also finds that the highest increases in wage returns occurred in jobs that require both a high level of mathematics and high social skills, indicating that the complementarity of certain skills gains in importance. This finding is also supported by evidence from Sweden where rising returns to non-cognitive skills since the 1990s have been most pronounced in the upper part of the wage distribution (Edin et al. 2017). Hence, the highest returns to skills both in terms of job prospects and wages seem to increasingly hinge not only on cognitive, but also on (complementary) non-cognitive skills and personality traits.

One potential reason for the rising relevance of non-cognitive skills is that the need to coordinate production processes both within and across workplaces increased due to a rising complexity and interconnectedness of production processes both within and across firms, highlighting the role of *reinstatement effects* (see section 0). Moreover, such changes in work organisation are likely to increase skill requirements along a number of dimensions. In line with this, recent results from a survey among German firms suggest that new technologies raise the demand for process know-how and interdisciplinary thinking, as workers have to keep an overview of more and more machine-driven processes that are becoming increasingly complex (Arntz et al. 2016c). Also, a report by the Fraunhofer Institute for Industrial Engineering indicates that the changing organisation of production processes in the digital age affects workers' tasks and work organisation and increasingly leads to a convergence of the classical production worker and the knowledge worker (Ganschar et al. 2013). In line with this, job complexity, i.e. the variety of tasks performed in a job, increased since the 1980s, especially among low- and medium educated workers such that initial differences between high and less skilled individuals have been levelled out (Pikos and Thomsen 2016).

Hence, skill requirements seem to rise in a number of dimensions and the demand for skillsets that combine technical skills, problem-solving skills, analytical skills, system skill, process skills and social skills seems to gain in importance (Cedefop 2018, ch. 6, World Economic Forum 2016, Berger and Frey 2016, Hammermann and Stettes 2015). In line with this, a study based on foresight methods such as the Delphi technique identifies a list of skills that reflects this increasing complexity of skill requirements in the digital era, including skills such as social intelligence, novel and adaptive thinking, cross-cultural competency, computational thinking, new media literacy, transdisciplinarity, design mindset[8], cognitive load management[9] and virtual collaboration[10] (Davies et al. 2011).

[8] Refers to the ability to represent and develop tasks and work processes for desired outcomes.

However, although non-cognitive skills seem to gain in importance, the rising demand for IT skills and the related mismatch between the supply of and demand for these skills seems to be an exception. While digital skills, especially advanced skills that correspond to developing and programming software or applications or using computer syntax or statistical analysis packages, are increasingly important, the vast majority of workers uses much lower IT skills or does not use digital skills at all (Cedefop 2018). The latter group disproportionately comprises female, low-skilled and older workers. Since access to well-paid jobs in the future may increasingly depend on at least a moderate level of digital proficiency, the digital skill gap may severely impair the job prospects of a large share of workers. In support of this, Falck et al. (2016) and Lane and Conlon (2016) find substantial returns to ICT-literacy, i.e. the ability to solve problems using ICT-based applications (e.g. Internet browser, email, word processing, spreadsheet tools) based on the PIACC database, suggesting that a lack of such skills may severely impair wage prospects. In fact, Lane and Conlon (2016) even find evidence that IT skills can compensate for the lack of higher formal qualifications while the opposite does not hold. But even among those already using advanced digital skills on a daily basis, the need for continuous updating of their skills is most relevant as digital skills appear to be particularly prone to becoming outdated (Cedefop 2018). Hence, the ability to learn and to adapt to new technological environments turns out to be a key competence in the digital era.

While on the one hand, we thus see a clear trend towards rising skill requirements in a number of complementary dimensions, there is also an ongoing debate that, at least for a certain share of the workforce, skill requirements might actually decrease. Concerns that automation technologies in manufacturing might actually result in less qualified jobs have already been voiced in the early 2000s (Mittal and Pennathur 2004). Recently, Steil und Maier (2017) discuss how the use of a new generation of cooperative robots may lead to a deskilling of workers if the assistance of increasingly intelligent and interactive robots leaves only simple tasks to human users. Similarly, Flecker et al. (2016), argue that the use of devices with augmented reality might degrade workers to robot-like task providers who are directed by information technologies, leaving them with almost no autonomy. However, deskilling has also been discussed in the context of typical white-collar or service jobs. Howcroft and Richardson (2012) discuss that back office work has been subject to an IT-enabled standardisation such that work could be restructured into shared service centers that provide standardised services for the entire company rather than being located in different parts of the company. Hence, what had previously been tacit, i.e. experience-based, knowledge was devalued, as much of this tacit knowledge was codified within software systems. As a consequence, high-skilled back office jobs were transformed into less skilled service jobs that were also increasingly competing with external providers of similar services. Similarly, Carter (2011) shows that the introduction of a digital work flow that aimed at standardising and fragmenting the tax processing in the UK civil service for the purpose of increased efficiency, left each tax officer with only a single standardised task, strongly reducing the skill requirements of the clerical worker involved. According to a related case study by Rinta-Kahila et al. (2018), the loss of skills among the workforce in an IT firm was only revealed by the disruptions this caused after the firm had stopped using an automated accounting and reporting system. This is also consistent with an experimental study that shows that the use of knowledge management systems may worsen workers' explicit knowledge about work processes (McCall et al. 2008).

Despite the debate on such deskilling trends, there is lack of evidence regarding the large-scale relevance of this phenomenon. In a recent survey among German workers, for example, almost 30 percent of low-skilled workers, but only 3 percent of high-skilled workers reported declining skill

[9] Refers to the ability to discriminate and filter information for importance, and to understand how to maximize cognitive functioning using a variety of tools and techniques.

[10] Refers to the ability to work productively as a member of a virtual team.

requirements at their workplace. Moreover, the need for constantly advancing ones skills was supported by more than 80 percent of high-skilled workers, but only two thirds of low-skilled workers (Arnold et al. 2016). This suggests that employment polarisation (see section 0) is accompanied by a polarisation of skill requirements which likely raises the hurdles for low-skilled workers to climb up the career ladder.

Work Organisation

The AR framework discussed in Section 3.1 involves various channels through which technology affects employment. Many of these channels imply substantial changes to the organisation of work. For instance, the substitution of technology for human labour *(displacement effect)* changes the division of work between humans and machines and, ultimately, job design. Also, the adoption of new technologies lowers the costs not only for production but also for communication, monitoring and supervision (*productivity effect*), thus affecting organisational structures and the boundaries of firms. Furthermore, new technologies enable new business models leading to the introduction and expansion of new tasks (*reinstatement effect*). As Bresnahan, Brynjolfsson and Hitt (2002) state, firms do not simply invest in new technologies to achieve service quality and efficiency gains. Instead, they go through a process of organisational redesign and make substantial changes to their product and service mix.[11] According to Aubert, Caroli and Roger (2006), organisational redesign is often targeted at more flexibility and may involve self-managed teams, multitasking, just-in-time production and delivery, total quality management and some decentralisation of decision-making. Similarly, Lindbeck and Snower (2000) ascribe the restructuring process to an increased role of team work and job rotation, a reduction in the number of management levels, continuous learning and development of complementary skills, decentralisation of responsibility within firms, and direct participation of employees in decision-making on multiple fronts. Existing empirical work on this topic is still scarce and focuses mainly on the impact of information technologies (3rd Industrial revolution). Nevertheless, several insights can be drawn from these studies regarding organisational transformation in light of more recent technologies such as robotics and artificial intelligence (4th industrial revolution) and expected changes for the future of work.

One line of research looks at the link between IT investments and organisational change to show that they are complements in firms' production technology (for an overview see Brynjolfsson and Hitt 2000). This research is motivated by the observation that organisational design practices are clustered, meaning that the adoption of practices is correlated across firms so that some sets of practices consistently appear together (Athey and Stern 1998). For instance, Bresnahan et al. (2002) find that greater levels of information technology are associated with organisational change including increased delegation of authority to individuals and teams, greater levels of skill and education in the workforce, and greater emphasis on pre-employment screening for education and training. These complementarities may be explained by new technologies which substitute for jobs involving rule-based decision making and complement jobs involving nonprocedural cognitive tasks (see Section 0).

Conclusions for work organisation may also be drawn from studies investigating the impact of information technology on firm productivity. For instance, Black and Lynch (2001) find that new technologies are associated with higher productivity and that higher productivity levels can be

[11] Some scholars even see the lack of necessary organisational structures as one reason for why technology investments have not increased productivity in the way one would have expected (Caroli and Van Reenen 2001).

achieved by allowing greater employee voice in decision-making. Bartel et al. (2007) study the valve manufacturing industry suggesting that investments into a new technology led to a customisation of products and services. In particular, they find new IT investments to improve the efficiency of all stages of the production process by reducing setup times, run times, and inspection times, thus making it less costly to switch production from one product to another. The authors further find that these developments coincide with changes in workplace organisation, increasing the skill requirements of machine operators towards technical and problem-solving skills (compare to section 0). Both studies are in line with Lazear and Gibbs (2014, page 215ff) who argue in favour of a trend towards job enrichment resulting from two developments. First, IT speeds up communication and decision making, which reinforces the trend towards time-based competition and shorter product cycles. Second, IT also makes customisation cheaper, encouraging firms to adopt more complex product lines. Both foster a trend towards job enrichment.

Another line of research looks at the effects of technology on organisational structures directly suggesting that technological advances foster a trend towards less hierarchy and more flexible organisational forms, which generally involves workplaces with a wider range of tasks and more decision-making authority. For instance, Brynjolfsson et al. (1994) find on a sectoral level that investments in information technology led to a shift of the economy towards smaller firms. Reasons put forward by the authors are reductions in coordination costs and labour substitution, thus leading to greater outsourcing and leaner internal staffing. A further study by Rajan and Wulf (2006) find that hierarchies within firms are becoming flatter and that information technology is one major driver of this development, although this is not tested directly. According to the authors, these findings cannot simply be interpreted as a clear indication of decentralisation tendencies in response to technology. On the one hand, the authors find that decision-making authority is being pushed further down the organisation, a form of decentralisation. On the other hand, CEOs are getting more connected deeper down in the organisation, a form of centralisation. A more recent study by Acemoglu et al. (2007) analyse the relationship between the diffusion of new technologies and the decentralisation of firms showing that decentralisation is driven by firms closer to the technological frontier, firms in more heterogeneous environments, and younger firms.

Assessing the direct impact of technology on decision-making and delegation in organisations is another related field of study allowing implications on work organisation. For instance, Bloom, Garicano, Sadun, and Van Reenen (2014) study the impact of ICT on decision-making in organisations. The authors thereby distinguish between "information" and "communication" technologies. According to the results, communication technologies that lead to falling communication costs tend to reduce employee autonomy, as decisions are passed up the firm to higher managers. In contrast, information technologies that lead to falling information costs facilitate more effective employee decision making. A further study by Sun (2017) looks at how IT transforms the way work is performed by employees and how it facilitates working processes and practices that affect the decision-making of individual performance. The results suggest that IT use by individual users in an organisation is associated with better coordination in working processes as well as higher autonomy which, in turn, facilitates better decision making. Finally, the decision-making process could further change in the course of data-driven decision making (DDD), as suggested by Brynjolfsson and McElheran (2016). The study shows that DDD has tripled between 2005 and 2010 to 30 percent and provides evidence suggesting complementarities between DDD and both IT and worker education.

A further line of research investigates the effects of technology on job design, showing that new technologies change the division of labour between man and machine along the lines of tasks, skills or occupations. For instance, Gibbs (2017) postulates: (1) big data and machine learning are increasing machine's ability to perform cognitive, physical, and even some social (language) tasks; (2) greater access to data, analysis tools, and telecommunications allows many workers to focus more on social interactions, collaboration, continuous improvement, and innovation; (3) technology makes many high-skill jobs more intrinsically motivating, enabling more tasks, skills, and decentralisation. On the other hand, he also states: (4) machines substitute for humans in many manual and routine jobs; (5) technology has lowered the demand for mid-skill workers and increased value for high-skilled workers, (6) technology makes many middle-skill jobs less intrinsically motivating, with fewer tasks and skills, and more centralisation and monitoring. A further study by Doms et al. (1997) shows that plants that use a large number of new technologies employ more educated workers, employ relatively more managers, professionals, and precision-craft workers, and pay higher wages. However, the longitudinal analysis shows little correlation between skill upgrading and the adoption of new technologies. It appears that plants that adopt new factory automation technologies have more skilled workforces both pre- and postadoption. The results stand in sharp contrast to the strong positive correlation between changes in workforce skill and computer investment found in industry-level studies.

The above research is in line with work showing that organisational changes related to IT investments are skill- and age-biased. For instance, Caroli and Van Reenen (2001) investigates the determination and consequences of organisational changes (OC) in a panel of British and French establishments and find evidence for the hypothesis of a "skill-biased" organisational change. In particular, they find that organisational change reduces the demand for unskilled workers in both countries. The complementarity between skills and organisational changes is thereby argued to be the result of the following advantages of skilled workers: (1) they are better able to analyse and synthesize new pieces of knowledge, (2) training them to multitask is cheaper which enhances firm's reactivity to market changes, (3) they are more autonomous and less likely to make mistakes and (4) they are more likely to enjoy job enrichment. Aubert et al. (2006) provide further evidence suggesting that new technologies and workplace practices are age-biased. In particular, they find that new technologies tend to increase hiring opportunities much less for older workers than for younger ones and even decrease hiring for older workers in the case of computer use. The authors make skill obsolescence or adaptability problems of older workers responsible for their results.

New forms of work

The AR framework discussed in Section 3.1 also brings about new forms of work. For instance, the reduction of costs (e.g. for communication, monitoring or supervision), work standardisation and fragmentation of work (*productivity effect*) have induced trends towards outsourcing tasks. Second, new business models have created new organisational forms including new tasks and new ways in which tasks are performed (*reinstatement effect*). These developments are reflected in a large increase of alternative work arrangements. For instance, Katz and Krueger (2016) conduct a survey for the US and find that the percentage of workers engaged in alternative work arrangements – defined as temporary help agency workers, on-call workers, contract workers and independent contractors or freelancers – rose from 10.7 percent in February 2005 to 15.8 percent in late 2015. According to the study, this accounts for almost the entire net employment growth in the US economy. Similarly, a study by the OECD looks at the time period 2007-2013 and finds that the share of non-standard work in many OECD countries' workforce is significant and growing (OECD 2016a).

The increase in alternative work arrangements is unlikely to be driven by supply-side factors such as a shift in the workforce composition towards groups with a greater preference for alternative work arrangements (Katz and Krueger 2016). Also, weak labour markets with little bargaining power and few options for traditional employment do not seem to explain the broader trend (Katz and Krueger 2017). More likely are explanations related to technological changes making it easier for firms to contract out work. In fact, Kratz and Krueger (2016) find that the largest increase in alternative work arrangement is among workers hired through contract firms. The results are in line with the general evidence speaking in favour of a rise in domestic outsourcing, as for instance demonstrated by Goldschmidt and Schmieder (2017), as well as evidence showing a rise in the segregation of similarly skilled workers across employers and the increase in positive assortative matching of high-wage workers and high-wage employers (Song et al. 2016).

There are several possible technology-related explanations for the rise in alternative work arrangements through increased outsourcing. First, recent technological change leads to stronger work standardisation and disintermediation of work tasks, and reduces monitoring and supervisory costs, thus making contracting out easier. Second, higher competitive pressure increases firm demands for flexibility, such that firms increasingly hire specialised (self-employed) contractors for non-core activities as for instance janitorial, food, legal or IT-related services. This explanation is in line with the literature on work organisation suggesting that technological advances foster a trend towards more flexible organisational forms (see Section 3.2.2). A third explanation is that higher inter-firm variability in profitability – which might also be the result of technological change – sets incentives for firms to contract out work in order to restrict the pool of workers with whom to share the rents with.

A further related trend explaining the rise of non-alternative work arrangements is the emergence of platforms, often referred to as “gig”, “on-demand”, “platform” or “sharing economy”. These platforms serve as brokers between workers and firms and lead to a new organisation of work, particularly raising opportunities for firms to outsource work and which create new opportunities for self-employment (OECD 2016a). Although the online gig workforce is relatively small compared to other forms of alternative work arrangements, the share is growing very rapidly (Farrell and Greig 2016). Pesole et. al. (2018) report on average 10% of the adult population has ever used online platforms for the provision of some type of labour services. However, main platform workers - defined as those who earn 50% or more of their income via platforms and/or work via platforms more than 20 hours a week - account for about 2% of the adult population on average.

Alternative work arrangements, including those increasingly offered by platforms, provide firms and workers with many new opportunities. On the one hand, they can provide workers with a larger flexibility in terms of when, where or how to work as well as alternative income sources. For instance, Hall and Krueger (2018) show that that drivers who partner with Uber appear to be attracted to the platform largely because of the flexibility it offers, the level of compensation, and the fact that earnings per hour do not vary much with the number of hours worked. Katz and Krueger (2017) report that the share of US workers reporting income from self-employment nearly doubled from 8.7 to 16.5 percent between 1979 and 2014. Farrell and Greig (2016), however, note that platform earnings remain a secondary source of income and that reliance on platform earnings did not increase for individuals over time. Nevertheless, the authors conclude that platform earnings can help workers smooth fluctuations in other sources of incomes.

On the other hand, non-standard work arrangements may be associated with lower wages and incomes, less employment and income stability and lower health. For instance, Katz and Krueger (2016) find that workers in alternative work arrangements earn considerately less than do regular employees with similar characteristics and in similar occupations. The earnings gap is thereby largely driven by the fact that workers in alternative work arrangements work fewer hours. Similar results are found for a range of OECD countries (OECD 2015). Also, Goldschmidt and Schmieder (2017) find that wages in outsourced jobs fall by approximately 10-15% relative to similar jobs that are not outsourced. In contrast, Hall and Krueger (2018) find that Uber driver-partners earn at least as much as taxi drivers and chauffeurs, and in many cases even more. Moreover, alternative work arrangements may entail less predictable incomes, as suggested by the Upwork (2017) study on freelancing. According to their survey, freelancers’ three biggest concerns are about income predictability, being able to find enough work and being able to make it on one’s own. As a consequence, alternative work arrangements can be associated with lower health, increased anxiety, delayed household formation and larger social isolation (Lewchuk 2017).

Altogether, technological advances and related new forms of work bring along several opportunities and challenges. Whether the potential benefits outweigh the potential threats depends on the individual work relationship. While the balance remains uncertain, high-skilled workers more often seem to voluntarily choose such work arrangements to their individual benefit, whereas low-skilled workers more often seem to lack alternatives, suffering from the disadvantages of non-standard work arrangements (Spreitzer et al. 2017).

Worker preferences

Trends in alternative work arrangements may also be the result of changing worker preferences such as higher demands for more freedom and flexibility as well as a better work-life balance (Katz and Krueger 2017). For instance, according to the Upwork (2017) study, the five top reasons for freelancing are (1) to be one's own boss, (2) to have flexibility in the schedule and (3) to be able to choose one's own projects, (4) to work from the location of one's own choosing and (5) to earn extra money. Asked about the feelings related to freelancing, respondents of the Upwork study overwhelmingly answered that freelancing makes them feel good, independent, free and in-control. The survey results are in line with research on how workers value flexibility. For instance, according to Katz and Krueger (2016) a majority of workers who are independent contractors or freelancers value the flexibility and independence that comes with being their own boss and report that they would prefer to work for themselves rather than for someone else. Similar evidence comes from recent studies on the ride-sharing company Uber suggesting that Uber-drivers value the flexibility of platforms including the ability to set a customised work schedule and to adjust the schedule in real time (Chen et al. 2017). A somewhat different conclusion is reached by Mas and Pallais (2017) who analyse the value of flexibility of alternative work arrangements including flexible scheduling, working from home, and part-time work, suggesting a low average willingness to pay for flexibility overall, although there was a substantial right tail of individuals whose willingness to pay was larger. They also find that job applicants have a strong dislike for jobs with substantial employer discretion in scheduling, speaking in favour of a large disutility for evening and weekend hours.

Further studies that investigate workplace practices targeted at worker preferences for more freedom and flexibility include Beckmann, Cornelissen and Kräkel (2017) who examine the impact of self-managed working time (SMWT) on employee effort and find modest increases in employee's effort. According to the authors, intrinsic motivation amplifies the effort effect of SMWT. The result is in line with Henly and Lambert (2014) who find for lower wage workers in the retail sector that unpredictable work timing exacerbates work-life conflicts. Other studies focus on home-based work or telecommuting. For instance, Bloom, Liang, Roberts and Ying (2014) look at the effects of working from home within a Chinese experiment. They find significant gains from working from home in terms of worker productivity and satisfaction. This may be partially a result of the firm's careful monitoring of telecommuting workers. Dutcher (2012) further conducts an experiment and shows that working outside the office has positive implications on productivity of creative tasks but negative implications on productivity of dull tasks. The results suggest that not all tasks are suitable for being conducted outside the office. Finally, Kelly et al. (2014) finds that targeted workplace practices significantly reduce employee work-family conflict, and lead to improved family-time and schedule control.

Policy challenges from the digital revolution

The previous sections have given an overview of our most recent understanding of the impact of digital progress on labour markets. This section identifies some of the main policy areas that follow from this overview, in particular education and training policies, labour market policies, income policies, and technology regulation policies. We focus on policies that directly stem from the substitutability between new technologies and differently-skilled workers, and the countervailing effects of technological progress that work through changes in labour and product markets.

Education and training policies

All levels of education

The direct threat of automation is much larger for workers with low- and medium skill levels than for skilled workers (Acemoglu and Autor 2011). Consequently, technological progress is leading to substantial returns to education in many advanced economies (Autor 2014). Investing more and more efficiently in education would address this, thereby increasing the supply of high-skilled workers and dampening the rise in the skill premium, which is a major component of overall rises in wage inequality (Autor 2014). This requires policies to improve the *quality and labour-market relevance of education systems at all levels*.

At EU level, the 2018 Council Recommendation on Key Competences for Lifelong Learning is focused on improving the development of key competences for all people and calls Member States to prepare people for changing labour markets. The Commission is currently supporting efforts to develop a European Education Area.

At national level[12], many countries have taken measures to enhance and modernise their education systems in recent years. These include, for example, the new teacher remuneration model in Latvia, the professional development programmes in Italy and Denmark, or improvements in the attractiveness of teaching professions through raising salaries (as done by Lithuania, among others). Other policy strategies focus on maximising quality and efficiency of general education (Latvia), measures to develop quality in primary education (Luxembourg), curricular reforms to improve content and better incorporating transferable skills (such as in Croatia). In this context steps to increase the overall efficiency of public spending in education are particularly important (EC 2017c). Spending reviews on education have been carried out in Malta and Slovenia and are on-going in Portugal.

Digital skills can protect skilled as well as unskilled workers from automation. For example, the European Commission´s Digital Education Action Plan (EC 2018c) reports that 90% of jobs require some level of digital skills (EC 2018a). Consequently, more specific policies for developing digital skills are being implemented. In the context of the New Skills Agenda for Europe, efforts have been made to increase the number of digitally-competent teachers and schools. The European competence framework for Digital Competence (DigComp, EC 2017d) and the Self-reflection tool

[12] The information on policies at national level presented in this section comes partly from the 2017 European Semester Country Reports, (see EC 2017a,b).

for digitally capable schools (SELFIE, EC 2018b), an initiative for assessing and developing schools' digital capacity, are examples of EU policy interventions in this area.

Actions from Member States include covering digital skills in education plans and curricula (Germany, Austria), teacher training (Germany, Croatia), teachers' access to ICT equipment (Austria) and the use of e-content in classrooms (‘ -Schools’ project, such as in Croatia), or the development in Ireland of a full Digital Learning Framework for school professionals.

Higher education, vocational education and training

In order to address the shortage of high-skilled labour due to ongoing technological progress, particular efforts are required in the area of higher education. At EU level, *increasing tertiary education* attainment is one of the main targets of the Europe 2020 strategy. Also, in 2017 the European Commission adopted a renewed agenda for higher education with initiatives to stimulate cooperation with employers; foster international mobility of students; further standardise skill qualifications; increase transparency; enhance monitoring of graduates' employability; and improve quality of teaching.

At national level, some examples of measures to enhance higher education include Estonia's revision of the tertiary education funding model to improve stability of funding and improve performance-based indicators, the inclusion in Lithuania of elements that reward quality and an independent national accreditation agency, or the link between the funding to teaching quality in the new Teaching Excellence Framework planned to be introduced in the UK from September 2019.

There is a widespread belief that we should raise the share of graduates who choose Science, Technology, Engineering and Math (STEM) to further strengthen the complementarities between technology and worker skills. Given ongoing digital progress, there is a particular need for digital skills as part of STEM education and training. STEM graduates on average earn more than other graduates (Daymont and Andrisani, 1984; James et al., 1989; Grogger and Eide, 1995; Arcidiacono, 2004) and are less likely to be overqualified (Dolton and Vignoles, 2000; Frenette, 2004; McGuinness, 2006).

There also exists evidence that the social returns to STEM graduates exceed their private returns through human capital externalities (Winters 2013). This suggests that policy could focus on raising the share of graduates in STEM fields and on improving the matching of skills between curricula and business practice.

The above-mentioned EU renewed agenda for higher education also includes measures to attract more students into STEM fields, medical professions and teaching. At national level, Member States like Denmark are reforming the general upper secondary education boosting the learning of mathematics and natural sciences. Netherlands is engaged in a National Technology Pact 2020 to address the demand for STEM graduates in the labour market[13]. Latvia has introduced diagnostic tests in STEM subjects in basic and upper secondary education. In the UK, the Industrial Strategy green paper published in January 2017 proposed new capital funding of GBP 170 million (EUR 208 million) for Institutes for Technology, in order to tackle shortages of STEM skills.

Some policy strategies have also been centered on *matching skills in education and business practice*. Comprehensive national skills strategies can help in this endeavor. This requires developing tools to better monitor and forecast skills needs, as highlighted in the New Skills Agenda for Europe.

[13] Van den Broek, Deuten & Jonkers (forthcoming)

The Blueprint for Sectoral Cooperation on Skills (EC 2017e) as part of this Agenda also provides a new framework for strategic cooperation to address skills gaps in a given economic sector between key stakeholders under Blueprint Alliances (EC 2017f)**.** At national level, countries like Poland and Estonia have introduced public systems for monitoring and forecasting labour market needs and skills, and Lithuania has adopted a diversity of actions in the higher education and research system to better match labour market and skills (see **Box 1** for more details).

In addition, the development of *vocational education and training* through apprenticeships and dual training is being widely implemented by Member States, often with the support of EU funds, to keep students' skills in line with changing demands for competencies due to technological progress. The promotion of dual training (Bulgaria), the involvement of employers in designing curricula and increasing the number of apprenticeships (Czech Republic), new types of apprenticeships tailored to labour market needs (Ireland, Cyprus), and the increase in the learning and qualifications component of apprenticeships (Italy) are examples of some measures taken. In Ireland, an Expert Group on Future Skills Needs (EGFSN) is advising the government on future skills requirements and associated labour market issues. Spain is engaged measures to strengthen the apprenticeships in the research, innovation and engineering field (see **Box 1**. for more details).

Box 1: Examples of measures matching skills in education and business practice

Lithuania adopted in 2016 a new law on higher education and research which provides for more cooperation on curriculum development with social partners and the expansion of work-based learning opportunities in tertiary education. New pathways from professionally-oriented programmes to traditional academic master's programmes will also be opened up due to this new law. Moreover, a national human resource monitoring framework plan has been approved covering all levels of education, including the observation of the labour market outcomes of graduates and forecasting of future skills needs (EC 2017h).

Spain is taking measures to foster cooperation between universities and business. The government has approved a number of fiscal incentives to help businesses to expand their limited innovation capacity by encouraging them to hire research staff and to offer apprenticeships to university and VET students. The government envisages expanding the dual model to higher education and some universities have already signed agreements with companies to develop dual training in engineering programmes (EC 2017i).

Lifelong learning

If technology optimists are right and the speed of technological change indeed accelerates, then workers will also be forced to adjust their skills to the changing requirements more frequently. Measures to raise further training along the life course, supporting life-long learning (LLL), may thus become more and more important to sustain employability, especially for low-skilled workers in non-standard work arrangements. This requires education and training systems which quickly adapt their curricula to the changing skill requirements. Moreover, workers require options, and potentially also the financial support and incentives, to participate in such measures (Arntz et al. 2016a). Such policy measures could preventively train workers, making them fit for changing skill requirements before they become unemployed. This particularly holds for low-skilled workers and older workers who – despite typically being most exposed to automation – on average participate the least in training (Albert et al. 2010, Bassanini and Ok 2004). Studies indeed show that training raises the employability of these workers (Sanders and de Grip 2004).

Lifelong learning also has a major role to address the need for education and training to adapt the skills of workers to the digital revolution. Last developments at EU level in this line are mentioned above. At national level, many Member States have been focused on implementing a diversity of life-long learning programs along these lines. For example, Austria (**Box 2**), Bulgaria, Croatia, Portugal and Cyprus have recently taken measures to increase participation of adults in lifelong learning programmes. In Sweden, for example, workers can use an unlimited educational leave to participate in training and qualification measures that entitles them to return to their pre-leave job (Schulte-Braucks 2013).

Other measures include the assessment of skills and competences of unemployed people (Malta) or their skilling in growing economic sectors (Ireland, **Box 2**), incentives to promote in-company training for older workers (Belgium), financial support for companies that invest in lifelong learning for their employees (Cyprus), improved qualification services for adults (Portugal, **Box 2**) or attaching training rights directly to workers (France).

Box 2: Examples of Life Long Learning Programmes

In Austria, the Educational guidance and counselling initiative is promoting the extension and further development of cost-free educational guidance and counselling for adults. Moreover, the Act on an education and training obligation until the age of 18 provides a framework for upgrading the skills of disadvantaged young people, and the planned standardised forms of partial qualifications aim at improving the educational achievement of learners (EC 2017j).

Ireland launched the Springboard+ programme in June 2016 to upskill and reskill the unemployed to find employment in growth sectors of the economy. The programme provides free part-time and full-time higher educational opportunities to reskill and upskill jobseekers. Almost half the places are on ICT courses, reflecting the growing demand for these skills. ICT conversion programmes are open to people regardless of employment status. There are also a significant number of places on manufacturing courses (EC 2017k).

Portugal has established the so-called ‘Qualifica’ centres, replacing the previous network of specialised Centres for adult qualification and reinforcing them with upskilled staff. The government has also launched the ‘Qualifica passport’, a new online tool that not only registers the learning and competences, but also enables the understanding of what the adult lacks in order to achieve a certain qualification (EC 2017l).

Labour market policies

Public and private employment agencies

Technological change alters the structure of jobs, imposing high costs on workers to learn new skills or change jobs. This mismatch between skills and technologies not only slows down the adjustment of employment and wages but holds back potential productivity gains from new technologies (AR).

Public and private employment agencies can help mitigate these costs of labour adjustment for both workers and firms. For example, policies can help various offline and online job matching platforms to improve the job finding probabilities for job seekers and the probability to fill a vacancy for businesses. In particular, Autor (2009) shows how labour market intermediation can help to provide information to job seekers about relevant vacancies (and vice versa) to make the matching process more efficient; to mitigate adverse selection in labour markets where information about individual workers or employers is largely missing; or solve collective action problems in job markets that would otherwise unravel (e.g. when congestion of job seekers leads to a rat race between employers to fill vacancies). For example, Belot et al. (2016) provide experimental evidence showing the importance of information as barrier to occupational mobility: redirecting individuals towards tight labour markets increases their chance of getting a job interview. Goos et. al. (2018), show that such recommendations could be successful for unemployed job seekers affected by technological progress.

The impact of technology on the structure of jobs underlines the importance of policy interventions to facilitate and support transitions between jobs and fostering occupational mobility. An overarching initiative at EU level is the European Pillar of Social Rights, jointly proclaimed by the European Commission, the European Council and the European Parliament in November 2017 (EC 2017g). The Pillar sets out 20 key principles and rights regarding equal opportunities and access to the labour market, fair working conditions and social protection and inclusion. The Social Pillar reaffirms rights already present in the Union acquis and adds new principles to address the challenges arising from societal, technological and economic developments, including the digital revolution. These principles are being implemented through the European Semester of economic policy coordination and have been reflected in the new guidelines for the employment policies of the Member States.

A number of other measures have been taken in recent years at EU level to address these challenges. The European network of Public Employment Services (EC 2018f) was established in May 2014 to compare performances of public employment services across its Member States and to modernise processes of labour market intermediation. The introduction of the Youth Guarantee (EC 2018g) to battle youth unemployment and a specific Council recommendation with measures to tackle long-term unemployment (EC 2018h) are other important EU-level initiatives.

At national level, most Member States have adopted measures in recent years to improve the functioning and capacity of their public employment services.

For example, Greece and Hungary have introduced new profiling systems to allow a better targeting of active labour market policies. Cyprus has increased the capacity of its employment service by increasing the number of counsellors, and many countries have launched activation programmes targeted to young people (Cyprus, Bulgaria, Latvia, Estonia or the Netherlands-see **Box 3**), or the long-term unemployed (Denmark, Spain, Portugal), in line with the respective EU policy frameworks. Denmark has adopted a broad-ranging reform of its unemployment benefits system (see **Box 3**). Unemployment benefits are also being reformed to provide adequate income support during transitions (Latvia, Lithuania) while incentivising access to employment (Estonia, Finland, Cyprus, Slovenia, Belgium).

Box 3: Examples of measures to enhance activation, mobility and transitions

In the **Netherlands**, Step2Work practice is a joint venture of Dutch municipalities, public employment services and the social partners from the energy sector to prevent and tackle youth unemployment. Participants in the programme may enter a training path comparable to an apprenticeship. More than two-thirds of participants who completed the programme and obtained a qualification within one year are employed three months after obtaining their qualification (EC 2017m).

Denmark has adopted a broad-ranging reform of its unemployment benefit system which involves a significant simplification and digitalisation. It is now possible to prolong the duration of unemployment benefits if the beneficiary is taking short-term work. Furthermore, a new unemployment insurance scheme has been introduced for the self-employed and persons in non-standard jobs. In this new scheme, unemployment is defined in relation to activities rather than to a categorisation as either self-employed or wage earner. Income as both wage earner and self-employed as well as income from multiple income sources will establish eligibility and entitlements (EC 2017n).

Non-standard work

A key area for policy intervention is the emergence of new forms of employment linked to the development of new business models based on the introduction of technological innovations. The potential negative impact of atypical forms of employment on working conditions and the protection of workers is specifically addressed at EU level by the European Pillar of Social Rights, which covers all persons in employment, regardless of their employment status, modality and duration. In particular, the Pillar contains principles aiming at guaranteeing the right of workers to fair and equal treatment regarding working conditions and fostering innovative forms of work that ensure quality working conditions. It is also accompanied by a proposal for a Directive on Work-Life Balance for Parents and Carers and a proposal for a Directive on Transparent and Predictable Working Conditions (EC 2018i).

At country level, governments are starting to act to protect workers who are affected by worsening working conditions. The Netherlands and Finland have attempted to regulate the so-called "zero-hour" contracts.[14] In France, independent workers of collective platforms now enjoy full rights to demonstrate, set up or participate in trade unions. Romania, Hungary and Poland have also improved the conditions of various types of precarious employment. However, the evolving nature of these challenges and the lack of evidence on their nature and size can hamper effectiveness of policy interventions. Policy experimentation to respond to these issues is therefore warranted, including for example the idea, proposed by the Dutch government, to legally mandate employer-paid social security provisions for the rising group of self-employed falling below a certain hourly wage threshold, thereby recognizing the distinction between non-standard work arrangements at the bottom and top of the wage distribution.

[14] “Zero-hour” contracts are contracts where employers do not guarantee minimum hours worked and where workers are not obliged to work but may agree to be available upon request.

Income and tax policies

Income policies

Post-market policies of redistributing overall household income mainly involve direct and indirect taxes and transfers. These policies can help cushion the impact of labour market shocks which disproportionately affect some groups of workers, as well as protect job quality. Furthermore, there is growing evidence that more unequally distributed household income reduces intergenerational income mobility – e.g. it is more difficult for children from poor households to make a decent living later in life when income inequality is higher.[15]

Workers with non-standard arrangements often do not have the same income and social security protection compared to workers with standard employer-employee contracts. As platform-based work still is a small phenomenon despite large growth rates, there exists only little evidence on these threats or how to best address these concerns.

Job polarisation implies that a fraction of workers is being re-allocated from middle-paid to low-paid jobs. Given the lack of evidence that minimum wages destroy jobs[16], minimum wage policies can protect the income of a growing number of workers in low-wage jobs if not set too high. Moreover, recent evidence shows that hiring credits for minimum wage workers in France during 2008-2009 significantly increased their employment.[17]

Additionally, income security for low-wage workers can be organised through welfare-to-work programs that reduce the risk of poverty while incentivising individuals to do paid work, such as the Earned Income Tax Credit (EITC) in the US or the New Deal in the UK. The existing evidence suggests that EITC are indeed effective at raising labour market participation (Eissa and Hoynes 2006).

However, how adequate socio-economic policy responses should look like and whether workfare programs could be successful for the upcoming challenges remains unclear. Evaluations of previous workfare programs typically report little success (c.f. Dostal 2008, Handler 2003).

Tax and benefits systems are a key area for policy interventions to mitigate the social costs of the labour market adjustments due to technological progress. A particular emerging problem is linked to access to social protection of workers with atypical contracts. At EU level, the European Pillar of Social Rights recognises for the first time the right to social protection to workers (and, under comparable conditions, the self-employed) regardless of the type and duration of their employment relationship. To support this principle, the Commission has proposed a Council Recommendation on Access to Social Protection (EC 2018j).

Member States are starting to act to ensure access to social protection to all types of workers. A number of countries are taking measures to improve working conditions for the self-employed and ensure that they enjoy adequate access to social protection (Greece, Lithuania, Portugal, Italy, Spain,). Additional examples of policy interventions in this direction are provided in **Box 4**.

[15] See Corak (2006) and the discussion about the "Great Gatsby Curve" that followed.

[16] See Manning (2016) for an overview of the literature.

[17] See Cahuc, Carcillo and Le Barbanchon (2017).

Box 4 : Examples of measures to improve access to social protection

In **Denmark** the new unemployment insurance scheme for the self-employed and persons in non-standard jobs aims to better cover the growing number of new and combined forms of employment (EC 2017n).

In **Ireland** the government provides entitlement for the self-employed to receive invalidity benefits (as of 2017). It launched a survey among self-employed on how to reform the social protection system for them (EC 2017k).

In **Italy**, the Jobs Act on non-entrepreneurial self-employment and smart working, adopted on 9 May 2017, provides for the extension of protection measures to self-employed, including: maternity leave, parental leave, illness, unemployment benefit, deduction from taxable labour income of expenditure linked to vocational training (EC 2017o).

In **Croatia**, the tax reform which came into effect in January 2017 included an extension of social protection to non-standard workers, coupled with an obligation to pay social security contributions, which could however reduce the net value of income of some workers, such as artists and creative workers (EC 2017p).

In **Latvia**, taxi drivers and persons working for high-potential start-ups receiving state subsidies are now considered as employees instead of potential self-employed, which allows them to build up stronger social rights (through an Amendments to the Law on State Social Insurance, adopted in November 2016) (EC 2017q).

In **France**, the law of 9 August 2016 introduced, starting from 1st January 2018, the principle of social liability of collabourative platforms towards independent workers uses them as intermediary. Platforms will participate in work accidents insurance coverage (EC 2017r).

Efforts are being made to improve social protection systems while ensuring that they include appropriate incentives to work. Many Continental European countries have followed these programmes in different formats and with varying scope since the mid-1990s, but considerable room remains for further improvements and increases in scope[18]. Countries which have adopted measures along these lines in recent years include Ireland, Belgium, Austria, Malta, Romania. Greece, as well as Cyprus and Italy (see also **Box 5**) have taken steps to set up a guaranteed minimum income scheme. Linking entitlements to individuals rather than jobs may foster mobility and mitigate the social cost of labour market adjustments (OECD, 2017). The social protection reform recently adopted in France aims to advance in this direction through the creation of a system of personal accounts for workers. Besides France, several other Member States have indicated they consider introducing similar systems. See **Box 5** for more details.

Furthermore, there recently have been claims that basic income schemes should be introduced due to the threat of massive technological unemployment. While these threats are unlikely to come true, upcoming technologies may force workers to switch jobs or (re-)train more often. A basic income scheme might support such adjustment, although it is unclear whether these programs can ultimately be successful, as they could potentially strongly reduce work incentives particularly for low-skilled workers. So far, there exist no large-scale results on the work incentives of such a scheme. Marx and Peeters (2008) study winners of a Belgian lottery to get first insights and find no

[18] See Daguerre and Taylor-Gooby (2004) for a discussion.

large work-disincentives. Whether these results transfer to a larger scheme remains unclear. Currently, there are several experiments with basic income schemes underway, both in- and outside Europe[19]. Experimenting with novel solutions using Randomised Controlled Trials (RCTs) is an important way in which we can learn about new policies and their (dis)advantages.

Box 5: Examples of redistributive policies

Cyprus has introduced a guaranteed minimum income scheme. The implementation of the GMI and the streamlining of all benefits with specific criteria and control processes enabled a more effective allocation of benefits to those in need, avoiding the waste of valuable resources (EC 2017s).

In **Italy** the new 'Inclusion Income' scheme (reddito di inclusione) will define a basic level of social benefits guaranteed nationwide (EC 2017o).

The system of web-based, personal accounts with employment-related rights (compte personnel d'activité, CPA) presently being introduced in **France** puts together social protection and employment related systems. These CPAs improve the management of three social benefits: pensions entitlements due to arduous work and the 'time saving scheme'. The CPAs will allow people to use "points" accrued on past jobs for training, sabbatical/family leave, salary top-up, and more. Moving to a non-standard contract might entail accruing no further or fewer points, but the acquired "points" are not lost; conceivably these could even be used to finance a start-up into self-employment. Such personal accounts ensure more continuity in rights across job types and enhancing mobility. They would achieve a fuller take-up of social rights and to empower people to choose the benefits and services that fit best with their needs (EC 2017r).

Tax policies

Taxes that are higher for labour than for investments in capital can lead to the misallocation of workers and capital if both are competing to do the same tasks. Higher taxes for labour than for capital can lead to too low employment and too much capital accumulation from a social point of view. AR refer to this as 'excessive automation' and show that it is consistent with the recent decline in the labour share (i.e. the share of national income going to labour instead of capital) and the slowdown in overall productivity growth observed in the data.

Therefore, policies that shift taxes away from labour towards capital could increase the labour share and lead to stronger overall productivity growth. However, an important challenge for policy makers in doing this is to assess the appropriateness of such tax shifts, given that the accumulation of digital capital is in part taking place in markets that are characterised by various externalities. As an example, consider the possibility of increasing taxes for Facebook. Facebook's 2 billion active users suggest that it does create social value for those users as well as for companies advertising on the platform. Therefore, a social planner that taxes Facebook must also account for the impact of the tax on the surplus Facebook creates for its users and advertising companies. If Facebook increases the fee it charges to advertising companies in response to an increase in taxes it has to pay, fewer companies might decide to advertise on Facebook. In turn, this reduces the surplus for

[19] Currently, for example there exist basic income experiments, among others, in Finland (Kansaneläkelaitos 2017), Kenia (GiveDirectly 2018), or Ontario (Ministry of Community and Social Services 2017).

active users who value ads targeted to their preferences. Consequently, Facebook will attract fewer active users, which in turn attracts fewer advertising companies, hence fewer active users, etc. These network externalities could imply that increasing taxes for Facebook could generate much lower tax revenues for governments than expected.

Technology regulation policies

A much-debated question is whether today's non-routine labour tasks could soon be automated by ongoing advances in Robotics and Artificial Intelligence (AI) – see Brynjolfsson and McAfee (2017) for a recent discussion. For example, Pratt (2015) summarizes a number of key technologies in Robotics that are improving at exponential rates. In particular, he argues that algorithms embodied in robots are increasingly performing like the perceptual parts of the brain, such that robots are making large strides in their non-cognitive abilities such as human interaction and perception. Another example is O'Neil (2016) who illustrates the consequences of AI being implemented in labour markets, including its impact on our educational systems and through automated decision-making and screening in job search and hiring processes.

One policy implication thus is to better regulate the design and implementation of digital technologies. The success of most of today's machine learning algorithms is measured in terms of profit or efficiency, no matter their consequences for workers (and society more broadly). For example, AR show that technologies that limit the direct displacement of workers through automation while maximizing the productivity and reinstatement effects would generate most jobs. It is questionable whether AI, in which large investments are made at present, is such a technology. Given the many different applications of digital technologies, one good starting point for policy makers would be to invest in practice-based testing of worker interactions with automated systems such as online job platforms.[20] Based on this information, specific applications such as online labour markets can be regulated to better protect and help workers making use of them.

[20] An example is the Web Transparency and Accountability Project (https://webtap.princeton.edu/) at Princeton, creating virtual personalities that masquerade online to study the treatment they receive.

Conclusions

With the introduction of digital technologies into the work environment starting in the 1980s, the range of tasks that machines can perform has constantly expanded. With the most recent period of the digital revolution and advances in robotics and artificial intelligence, public fears have been growing that machines will make human labour obsolete and give rise to widespread unemployment. In this study, we revise evidence on the labour market consequences of the recent period of the digital revolution. Based on this, we identify policy challenges along key policy areas and provide examples of current policy responses to those challenges.

The survey of the evidence shows that recent technological change has mostly had little effect on the total number of jobs with some evidence hinting at small positive aggregate employment effects while others suggest small negative effects. However, these small net effects were accompanied by substantial restructuring of jobs. This restructuring thereby comes along with several changes in the content of work and how it is organised and performed, hence shaping the future of work.

First, technological changes lead to shifts in skill requirements for jobs. According to the review, technological change until the mid-1980s was mostly skill biased, raising the demand for highly skilled workers while worsening perspectives for low-skilled workers. This changed with the introduction of computers in the mid-1980s, which were particularly efficient at replacing workers in middle-paid cognitive and manual routine tasks. Hence, the labour markets polarised with declining employment perspectives and wages of replaceable, middle-paid, middle-skilled workers. Workers who managed to upgrade their skills in order meet the demands were able to benefit from the changes, while for other workers the changes implied downgrading to lower-paid jobs.

Second, technological adaption in firms is accompanied with a process of organisational redesign. The changes are often targeted at challenges related to shorter product cycles, customisation of products and services, more complex production lines, faster communication and decision-making as well as a new work division between humans and machines. As a consequence, IT-related organisational changes lead to more flexible organisational forms with less hierarchy and which generally involve workplaces with a wider range of more demanding tasks and more decision-making authority. The review suggests that such organisational changes ultimately result in job enrichment and are thus complementary to younger and highly skilled employees.

Third, new technologies bring along new forms of work. In particular, alternative work arrangements are on the rise and can largely be explained by trends towards outsourcing as a result of stronger work standardisation, fragmentation of work as well as reduced costs for monitoring and supervision. A further related trend explaining the rise of non-alternative work arrangements is the emergence of online platforms. Although the gig workforce is relatively small compared to other forms of alternative work arrangements, the share is growing rapidly, providing workers with new opportunities, but also new risks. Finally, trends in alternative work arrangements, especially freelancing, may also be the result of changing worker preferences such as higher demands for more autonomy and flexibility as well as a better work-life balance.

Whether the potential benefits of upcoming technological change outweigh the risks crucially depends on adequate policy responses. We outline four key policy areas which are affected. The policy issues at stake are wide-ranging and constantly evolving. The policy responses outlined in this paper focus on measures that could be effective in tackling some of the main emerging challenges.

First, education and training policies need to ensure that workers receive sufficient training and the right skills for the labour markets of the future. This requires a general rise in educational attainment and a better match of curricula with required skills, as well as reskilling and upskilling workers via life-long learning (LLL).

Second, active labour market policies are needed to address the mismatch between worker skills and changing skill demands due to technological progress. Public and private employment agencies can help mitigate the costs of labour adjustment for both workers and firms. The new technologies themselves can actually help employment agencies to reduce these costs via better information and matching algorithms.

Third, there is likely to remain a group of workers who, despite active labour market policies, will find it difficult to remain in work and, if so, to maintain the quality of their jobs. This calls for income policies targeted to less-skilled individuals, such as in-work tax credits for low-wage workers. Moreover, rising shares of non-standard work arrangements among low-wage workers further calls for an expansion of social insurance to these non-standard work arrangements.

Fourth, higher taxation of labour than capital results in a misallocation of productive resources: too few workers are employed at the expense of too much innovation. This misallocation of labour and capital contributes to the declining labour share and low productivity growth. Therefore, a tax shift from labour to capital could increase the labour share and productivity growth but increasing taxes on capital comes with major challenges for policy makers.

Fifth, policies that regulate investments in new technologies should focus on those technologies that minimize the direct threat of automation for workers and that maximize the positive countervailing effects that increase labour demand.

There are thus a number of policy areas to shape the impact of the digital revolution on labour markets, workers and the future of work and to ensure that the benefits from these new technological advances accrue to most people.

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