Oxford Review of Economic Policy, Volume 34, Number 3, 2018, pp. 362–375



# The impact of technological progress on labour markets: policy challenges

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**Abstract:** This paper gives an overview of current thinking by economists about the consequences of ongoing technological progress for labour markets, and discusses policy implications. In economics, the impact of technological progress on labour markets is understood by the following two channels: (i) the nature of interactions between differently skilled workers and new technologies affecting labour demand and (ii) the equilibrium effects of technological progress through consequent changes in labour supply and product markets. The paper explains how the ongoing Digital Revolution is characterized by a complex interplay between worker skills and digital capital in the workplace, and consequent changes in job mobility for workers and in output prices affecting consumer demand for goods and services. In particular, it explains how current worker–technology interactions and the equilibrium effects they entail combine to create economy-wide job polarization with winners and losers from ongoing technological progress. The paper therefore concludes by discussing a set of policy interventions to ensure that the benefits of the Digital Revolution are broadly shared.

**Keywords:** technological progress, occupational choice, policy

**JEL classification:** J24, J28, O30

## I. Introduction

We live in an age of automation and of automation anxiety—a combination that also occurred during previous waves of technological progress (see Autor (2015) and Mokyr *et al.* (2015) for overviews). In a widely circulated article, Frey and Osborne (2017) estimate that 47 per cent of all jobs in the US are 'potentially automatable over some unspecified number of years, perhaps a decade or two'. Using a similar methodology, other studies have come to similarly alarmist conclusions: McKinsey Global Institute (2017) argues that about 60 per cent of US occupations have at least 30 per cent of their tasks that will be automatable by 2055, while the World Bank (2016) estimates that almost 60 per cent of jobs in the OECD are susceptible to automation in the foreseeable future.

One limitation of these studies is that they exclusively focus on certain tasks currently done by workers and on how susceptible these tasks are to automation in the near

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I thank John Muellbauer, Abigail Adams, Anna Salomons, an anonymous referee, and seminar participants at Oxford University for excellent suggestions.

doi:10.1093/oxrep/gry002

future. However, as some tasks are being automated, this frees up time for workers to perform other tasks. For example, Arntz *et al.* (2016) argue that, within an occupation, many workers specialize in tasks that cannot be automated easily, and that once this is taken into account, only about 9 per cent of jobs in the OECD are at risk of automation. More generally, economists have recently developed a much fuller understanding of the broader impacts of the Digital Revolution on labour markets.

This paper therefore outlines the recent thinking by economists about the labour market impacts of technological progress. In particular, the impact of technological progress on labour markets is understood by working through the following two channels: (i) the nature of interactions between differently skilled workers and new technologies affecting labour demand and (ii) the equilibrium effects of technological progress through consequent changes in labour supply and product markets. The paper explains how the ongoing Digital Revolution is characterized by a complex interplay between worker skills and digital capital in the workplace, and consequent changes in job mobility for workers and in output prices affecting consumer demand for goods and services. In particular, it explains how current worker–technology interactions and the equilibrium effects they entail combine to create economy-wide job polarization with winners and losers from ongoing technological progress. The paper therefore concludes by discussing a set of policy interventions to ensure that the benefits of the Digital Revolution are broadly shared.

The remainder of this paper is organized as follows. Section II provides an overview of the recent thinking by economists about the consequences of ongoing technological progress for labour markets, and section III discusses implications for policy. Section IV concludes.

## II. The impact of technological progress on labour markets

Subsection II(i) discusses the nature of interactions between differently skilled workers and new technologies affecting labour demand. Subsection II(ii) discusses the equilibrium effects of technological progress through consequent changes in labour supply and product markets. Finally, subsection II(iii) discusses some alternative explanations that have recently emerged in the literature.

### (i) The interaction between differently skilled workers and technological progress

This subsection briefly discusses the three most important hypotheses that economists have used to examine worker–machine interactions: skill-biased technological change (SBTC); capital–skill complementarity (CSC); and the task assignment framework of routine-biased technological change (RBTC).[1] We briefly discuss each of these three hypotheses in turn.

[1] A fourth hypothesis is that of endogenous technological change, see Acemoglu and Restrepo (2016) and references therein. This hypothesis still awaits rigorous empirical testing, so it is not discussed further here.

The simplest framework for understanding the complementarity of worker skills and technological progress is a competitive supply–demand framework for skilled and unskilled workers. The SBTC hypothesis is based on the assumption that technological progress augments the labour productivity of skilled workers by more than it does that of unskilled workers, thereby shifting out the labour demand curve for skilled workers further than that of unskilled workers (Bound and Johnson, 1992; Katz and Murphy, 1992). The key insight from this simple supply–demand framework for differently skilled workers is that it predicts an increase in the skill premium (i.e. the wage of skilled relative to unskilled workers) when SBTC induces an acceleration in the demand for skilled relative to unskilled workers, and a decrease in the skill premium when there is an acceleration in the supply of skilled relative to unskilled workers. Note that only an acceleration (i.e. an increase in the growth rate) in the demand or supply of skilled relative to unskilled workers can result in a change in the skill premium, compared to steady and equal growth in the demand and supply of skilled relative to unskilled workers such that there is skill-upgrading in terms of employment but the skill premium remains constant (i.e. the supply and demand of skilled relative to unskilled workers shifts out to the same extent each period, leading to skill upgrading in terms of employment, but leaving the skill premium unaffected).[2]

Applying this framework to the data, Goldin and Katz (2009) show that the supply of skilled workers has risen dramatically in the past seven decades in advanced countries, yet wages of skilled workers have remained consistently above those of unskilled workers. In the US, for example, the college educated share rose from 6.4 to 29.7 per cent of the workforce from 1940 to 2000, whereas the fraction of those with less than a high school degree declined from 68 to 9 per cent. Yet, the skill premium in 2000 was at or above that in 1940, suggesting that, in the long run, the demand for skilled relative to unskilled workers must have accelerated too due to SBTC. Moreover, the observed short-run decline of the skill premium in the 1970s and sharp increase in the 1980s is in large part explained by an acceleration and then deceleration in the supply of skilled relative to unskilled workers, with the relative demand for skill due to SBTC growing steadily during both decades. In sum, a simple supply–demand framework of skilled relative to unskilled workers, also known as the canonical framework, goes a substantial distance towards explaining the evolution of employment and wage changes for skilled relative to unskilled workers.[3] At its heart is the SBTC hypothesis as a way to think about the interaction between technological progress and differently skilled workers.

The second hypothesis, known as the capital–skill complementarity (CSC) hypothesis, also considers a simple supply–demand framework for skilled and unskilled workers, but no longer assumes that technological progress is increasing labour productivity

[2] This corresponds to Tinbergen's (1975) race between technology (on the demand side) and education (on the supply side).

[3] There is considerable debate, however, as to whether the canonical framework can go an equal distance towards explaining differences in the skill premium between countries. For example, Blau and Kahn (1996) find that labour market institutions (in particular, labour unions and wage centralization) are much better predictors of cross-country differences in relative wages than are supply and demand indices constructed using education (for supply) and industrial and occupational composition (for demand). However, Leuven *et al.* (2004) use better data on skill levels to argue that differences in supply and demand can explain an important part of cross-country differences in skill premia.

by more for skilled than for unskilled workers as was the case for SBTC. Instead, the CSC hypothesis explicitly considers the role of capital as a third input factor in production (in addition to skilled and unskilled workers), and assumes that technological progress is best captured by a decrease in the price of capital over time. It then explores the possibility that the substitutability between capital and skilled labour is less than that between capital and unskilled labour, such that capital and skill are relative complements (Griliches, 1969; Berman *et al.*, 1994). Hence the name 'capital–skill complementarity' hypothesis. If this hypothesis is correct, capital deepening—i.e. the process of capital accumulation per worker due to a fall in the price of capital—will tend to increase the demand for skilled relative to unskilled labour. For example, Moore's Law captures the decline in the relative price of digital equipment, which could have stimulated capital deepening and thereby an increase in the skill premium due to capital–skill complementarity in the 1980s.[4] In particular, Krusell *et al.* (2000) build on the fact that the rate of decline of equipment prices may have accelerated sometime during the late 1970s to explain the increase in the skill premium that followed. Finally note that, just like SBTC, CSC also predicts an increase in the demand for skilled relative to unskilled workers as well as skill-upgrading in terms of employment due to technological progress.[5]

The final and most recent hypothesis is that of routine-biased technological change (RBTC), embedded in the task assignment model of Acemoglu and Autor (2011). Their model works to capture two forces that are central to understanding recent human–machine interactions.

(i) Technological progress is not increasing labour productivity (as in SBTC) or best captured by a decrease in the price of capital (as in CSC). Instead, the Digital Revolution is assumed to directly replace workers doing routine and therefore codifiable tasks. Hence the name routine-biased technological change.
(ii) There is self-selection of workers of different skill levels (low-, medium-, and high-skilled workers) across different tasks (least, middling, and most complex tasks) according to comparative advantage, as in Roy (1951).

Formally, Acemoglu and Autor (2011) assume that tasks inputs are imperfect substitutes in aggregate output, and each task is produced using labour from each of three skill groups (low-, medium-, and high-skilled workers), and capital, where each type of labour and capital are perfect substitutes but differ in their task efficiencies. In particular, comparative advantage schedules by skill type are supermodular in task complexity such that, in equilibrium, low-skilled workers are assigned to the least complex tasks, medium-skilled workers to middling tasks, and high-skilled workers to the most

[4] For example, Nordhaus (2007) estimates that between 1980 and 2006 the real costs of performing a standard set of computations, measured by the cost expressed in constant dollars or relative to labour costs, has fallen by 60 per cent to 75 per cent annually.

[5] There is a long-standing debate in the literature as to whether SBTC or CSC better captures the impact of technological progress on differently skilled workers. For example, Krugman (2000) makes the point that it is much harder to reconcile CSC than SBTC with the relatively slow growth in living standards since 1980. I do not want to go into this debate here, because the most important thing is that both hypotheses predict an acceleration in the demand for skilled relative to unskilled workers due to technological progress.

complex tasks.[6] The working hypothesis in Acemoglu and Autor (2011), then, is that digital capital has a comparative advantage in doing middling tasks because these tasks are routine intensive and therefore codifiable in software language, such that technological progress directly displaces medium-skilled workers from middling jobs. Consequently, some medium-skilled workers supply their labour to less complex tasks and others to more complex tasks.

Note that RBTC predicts that the Digital Revolution will lead to job polarization in employment, rather than skill-upgrading as was the case for SBTC and CSC. The process of job polarization implies that there is a u-shaped relationship between employment share changes over time and jobs (e.g. occupations with different task contents) ranked by their wage or educational attainment. Examples of low-wage jobs mainly done by unskilled workers are personal services such as cleaning or waiting tables in a restaurant. Middling jobs mainly done by medium-skilled workers are, for example, machine operators or office clerks. Examples of high-paid jobs mainly done by high-skilled workers are doing surgery or managing a team. The phenomenon of job polarization is the empirical observation that employment shares in high-paid but also low-paid jobs are rising, at the expense of middling jobs—see, for example, Autor *et al.* (2006), Acemoglu and Autor (2011), and Autor and Dorn (2013) for the US; Goos and Manning (2007) for the UK; and Goos *et al*. (2009, 2014) for Europe. The RBTC hypothesis is consistent with job polarization because easily codifiable routine tasks are concentrated in middling jobs, whereas high-paid jobs mainly involve doing non-routine cognitive and abstract tasks and low-paid jobs mainly involve non-routine interactive and manual tasks that, so far, have proven much harder to automate. Finally, note that the RBTC hypothesis assumes that digital capital can directly substitute for human labour, thereby allowing more easily for the direct automation of workers by digital innovation than the SBTC and CSC hypotheses.

### (ii) Equilibrium impacts of technological progress

It is intuitive to assume that technological progress not only changes relative labour demand, but also impacts on other parts of the economy. For example, in 1930 John Maynard Keynes wrote:

> We are being afflicted with a new disease of which some readers may not yet have heard the name, but of which they will hear a great deal in the years to come—namely, technological unemployment. This means unemployment due to our discovery of means of economising the use of labour outrunning the pace at which we can find new uses for labour. But this is only a temporary phase of maladjustment. . . . If one believes at all in the real values of life, the prospect at least opens up the possibility of benefit. (Keynes, 1930)

According to Keynes, capital accumulation would decrease labour demand, leading to technological unemployment. But this would only be a temporary phenomenon

[6] Intuitively, supermodularity refers to the assumption that the productivity differences between high-skilled and medium-skilled and between medium-skilled and low-skilled workers in doing a task are increasing in task complexity.

because, in the long run, an increase in income would also lead to satiation in labour supply to the benefit of 'real values of life' such as leisure time (i.e. the labour supply curve is backward-bending in the long run). That is, the initial increase in unemployment resulting from a technology-induced decrease in labour demand will, in the long run, be mitigated by a technology-induced decrease in labour supply.

In an overview article, Autor (2015) outlines two equilibrium channels that can mitigate or augment the impact of technological progress on employment and wages. The first are technology-induced changes in labour supply, as Keynes argued was likely to be the case. For example, if displaced middling workers abundantly supply the skills that are required in lower-paid occupations, the relative increase in low-paid work—i.e. job polarization towards the bottom—is larger. Moreover, if labour supplied to these low-paid occupations is relatively elastic, wage increases in lower-paid relative to middling occupations will be mitigated. A similar logic applies to the relative increase in high-paid work—i.e. job polarization towards the top. If it is difficult for middling workers to do the tasks required in higher-paid jobs, perhaps because they lack education, the relative increase in high-paid jobs will be lower and their relative wage increases higher.

The task assignment model with worker self-selection of Acemoglu and Autor (2011) formalizes this point. When capital directly displaces medium-skilled workers from middling to less complex tasks, the increase in the low-skilled/medium-skilled wage ratio depends on how strong the comparative advantage is for low-skilled compared to medium-skilled workers in doing simple tasks. If their comparative advantage is weak, increases in the low-skilled/medium-skilled wage ratio will be smaller because the elasticity of effective labour supplied by medium-skilled workers to simple tasks is higher. Similarly, RBTC increases the wage of high-skilled relative to medium-skilled workers depending on how strong the comparative advantage is for high-skilled compared to medium-skilled workers in doing complex tasks. If their comparative advantage is strong, increases in the high-skilled/medium-skilled wage ratio will be higher because the elasticity of effective labour supplied by medium-skilled workers to complex tasks is lower.[7] In sum, the RBTC hypothesis not only predicts job polarization because of the direct displacement of medium-skilled workers doing middling routine tasks, but also wage polarization that depends on technology-induced changes in labour supply.

The second factor outlined by Autor (2015) are technology-induced changes in relative output prices and real income depending on the price and income elasticities of consumer demand. Goos *et al.* (2014) decompose changes in occupational employment shares into within- and between-sector components to find that an important part of between-sector job polarization can be explained by technology-induced changes in relative product demand.[8] On the one hand, if middling industries are most affected by technological progress, these sectors will use less employment to produce a given level of output which will cause occupational employment shares to polarize even if output

[7] What happens to the wage of high-skilled relative to low-skilled workers is ambiguous and depends on how substitutable marginal low-skilled and medium-skilled workers are relative to marginal high-skilled and medium-skilled workers. For example, if marginal low-skilled workers have a strong comparative advantage in doing simple tasks relative to marginal high-skilled workers doing complex tasks, the wage of high-skilled relative to low-skilled workers will decrease.

[8] A well-known problem with decomposition methods is that they are unlikely to capture equilibrium effects. Goos *et al.* (2014) therefore use a decomposition rooted in a structural canonical framework.

shares do not. On the other hand, middling sectors will see a larger decrease in relative costs and output prices leading to a shift in product demand toward them. Goos *et al.* (2014) show that this latter effect attenuates between-industry job polarization but does not overturn it, because product demand is relatively price inelastic. A similar importance for technology-induced changes in product demand is found in Acemoglu and Restrepo (2017) and Gregory *et al.* (2016) to explain countervailing effects of technological progress on the level (rather than the structure, as is the focus of the job polarization literature) of employment; in Autor and Dorn (2013) to explain the recent rise in low-paid services in the US; and in Bessen (2017), who argues that employment in technology-maturing sectors will ultimately fall as demand for their products becomes satiated and therefore more price inelastic.

### (iii) Alternative explanations

Evidence suggests that job polarization was, by and large, pervasive across decades starting in the 1980s, but also that there are some differences between decades. In particular, earlier decades are characterized by stronger relative employment growth in high-paying sectors, whereas the period after 2000 is characterized by weaker relative employment growth in those high-paying sectors. Beaudry *et al.* (2016) document this twisting in employment shares for high-paying sectors using US data, and call it the 'Great Reversal'. Using a task assignment framework, their explanation relies on a boom-and-bust cycle in the dynamic demand for cognitive skills when a new technology is introduced. Intuitively, in an initial boom phase, employment in high-paid cognitive and low-paid manual tasks increases, whereas employment in middle-paid routine tasks and unemployment decreases. However, the marginal productivity and therefore investments in new technologies decrease as capital accumulates, leading to a decrease in the demand for high-paid cognitive and middle-paid routine tasks, and an increase in low-paid manual tasks and unemployment. Beaudry *et al.* (2016) provide some indirect evidence for this hypothesis and, if true, predict a continued pattern of skill-downgrading unless there is a new technological breakthrough that would start a new boom-and-bust cycle in the demand for skilled workers. In line with this, Deming (2017) finds that the share of STEM jobs (in science, technology, engineering, or mathematics) decreased in the US between 2000 and 2012, after growing in the previous two decades. However, he also finds an increase in STEM jobs that require social skills, attributing it to the specialization of skilled workers in coordinating team production following technological progress.

An alternative explanation for the relative increase in low-skilled jobs after 2000 is given by Grossman and Rossi-Hansberg (2008), who introduce a task assignment model of offshoring. In particular, they assume that advanced economies are increasingly offshoring unskilled jobs. Perhaps surprisingly, they argue that this increases the demand for domestic unskilled workers. The reason for this is that unskilled-labour-intensive sectors benefit disproportionately from offshoring, thereby increasing output and the relative demand for domestic unskilled workers. This increase in the relative demand for domestic unskilled workers is mitigated but not dominated by the direct delocalization of unskilled jobs abroad, or by an improvement in the country's terms of trade (i.e. an increase in the ratio of export to import prices that lowers relative demand for domestic unskilled labour if unskilled-intensive sectors are assumed to be importing sectors). However, the Grossman and Rossi-Hansberg (2008) model remains difficult to test empirically because few data exist on offshoring, and one could wonder whether it will be able to explain much of the relative rise in low-paid services as many of these jobs do not seem particularly offshorable. An alternative trade-related hypothesis is found in the influential work by Autor *et al.* (2013), who study the US employment impact of increased import competition from China, especially after its accession to the World Trade Organization in December 2001. They show that increased import competition from China decreased employment in manufacturing relative to services when the US increased its current account deficit with China after 2001. Given that many low-paid jobs are in non-tradable services, this could in part explain the patterns in employment share changes after 2000.

## III. Policy challenges for labour markets from digital progress

The previous section has given an overview of economists' understanding of the impact of technological progress on labour markets. Key insights were that the ongoing Digital Revolution is characterized by a complex interplay between worker skills and digital capital in doing certain tasks best captured by the RBTC hypothesis; by consequent changes in worker mobility towards jobs requiring different tasks; and by an economy-wide process of job polarization with winners and losers from ongoing digital progress.

Based on these insights, this section formulates relevant policy domains to deal with the challenges from the ongoing Digital Revolution for labour markets.[9] In particular, subsection III(i) focuses on challenges for workers' skills through education and training policies. Subsections III(ii) and (iii) discuss, respectively, labour market and income redistribution policies to ensure that the benefits of the Digital Revolution are broadly shared. Finally, subsection III(iv) discusses how technology regulation policies can help in creating technologies that are complementary to worker skills and that help mitigate its impact on economy-wide inequality.

### (i) Education and training policies

Autor (2014) provides evidence of increasing relative wages for the most-skilled workers in many advanced economies, which is a major component of overall rises in wage inequality. The evidence discussed in the previous section suggested that this is in large part driven by continuous shortages of highly educated technical workers due to ongoing technological progress.[10] Investing more in high-tech education would address

[9] It is important to note that the aim of this section is not to provide an exhaustive list of policy challenges or to discuss the effectiveness of specific policy instruments to deal with technological progress. Instead, the aim of this section is to use the literature discussed in the previous section to identify the relevant policy domains more broadly.

[10] Section II(iii) above discussed the slowdown since 2000 in employment share increases for high-skilled jobs that seems to occurring in advanced economies, suggesting that the current shortages of high-skilled

this concern, thereby increasing the supply of high-skilled workers and dampening the rise in the skill premium and overall inequality. However, World Bank data show no upward trend in government expenditures on higher education as a percentage of GDP in advanced economies after 1980, with many countries even reducing their expenditures during the recent Great Recession. In reaction to austerity in educational spending, higher-education tuition and therefore student debt have risen faster than inflation in many countries, making access to higher-education even more difficult and unequal.

At the EU level, a renewed agenda for higher education was adopted in May 2017. One of the aims of this agenda is to attract more students into science, technology, engineering, and maths fields, medical professions, and teaching. Other aims of this programme are to focus activities around real-world problems by stimulating cooperation between higher-education institutes and employers; to stimulate international mobility of students; to further standardize skills qualifications; to increase transparency about higher-education choices for students; and to invest in teacher quality. Although this renewed agenda for higher education could clearly address the concerns mentioned in the previous paragraph, it still requires substantial commitments and political will to be implemented.

The discussion in the previous section argued that the Digital Revolution not only leads to labour shortages for highly skilled technical workers. Consistent with the RBTC hypothesis, there also is an increase in the relative demand for workers with non-routine social, motivational, and interaction skills that, as of yet, have proven difficult to automate. The process of job polarization also learns that demand for these non-routine skills exists across many different occupations and sectors, including a growing importance of many low-paid service jobs. Regarding policy, a first implication is to better measure which of these non-routine skills at different levels of education are key to being successful in the labour market,[11] and how these skills can best be taught. In contrast to education policies promoting higher education especially in technology-oriented disciplines, much less progress is being made on implementing policies that invest in skills for all, including non-routine skills for less-educated workers in low-paid jobs.

### (ii) Labour market policies

It was explained in the previous section how the ongoing Digital Revolution entails changes in worker mobility towards jobs requiring different tasks. Public and private employment agencies can help mitigate these costs of employment churning 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 of filling a vacancy for businesses. In particular, Autor (2009) shows how labour

workers might be short-lived. However, the explanation given for this ‘Great Reversal’ was that the recent fall in the relative demand for high-skilled workers coincides with a slowdown in innovative activities, implying that more rather than less investment in high-tech skills is needed if one wants to sustain technological progress in the long run.

[11] The PISA and PIAAC surveys are good examples containing proxies of some of these non-routine skill measures, but the problem with these surveys is that they were not adequately designed to directly inform about the impact of digital innovation on the demand for non-routine skills at different levels of education.

market intermediation can help to provide information to job-seekers about relevant vacancies (and to businesses about relevant job-seekers) 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 to 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). To tackle some of these challenges, the European network of Public Employment Services was established in May 2014 to compare performances of public employment services across the EU's member states and to modernize processes of labour market intermediation, including the Youth Guarantee to battle youth unemployment.

Katz and Krueger (2016) show evidence that there has recently been an increase in non-standard work arrangements, such as interim, freelance, or contract work, especially in low-paid jobs that are becoming more important through the process of job polarization described in the previous section. Although many of these non-standard work arrangements and the fragmentation (or 'Uberization') of the workplace seem to offer more flexibility to workers, e.g. in hours worked, recent research suggests that most workers prefer stability and consistency in their work schedules (Mas and Pallais, 2017). Moreover, workers with non-standard arrangements often do not have the same income and social security protection as compared to workers with standard employer–employee contracts. At the EU level, the 2017 European Pillar of Social Rights is starting to address these issues. Other policies include 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.

### (iii) Income redistribution policies

The previous section discussed how the impact of the Digital Revolution on labour markets is uniquely characterized by an economy-wide process of job polarization. Through job polarization, ongoing digital progress results in winners and losers on the labour market, with an increasing fraction of households having to make ends meet from income from low-paid jobs. Furthermore, Corak (2006) provides 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 in a country is higher—a relationship that has become known as the 'Great Gatsby Curve'. One way to ensure that the benefits of the Digital Revolution are broadly shared across households is through changes in taxes and transfers. For example, it is questionable to tax labour income much more than capital income when workers and capital are competing for the same jobs.

Other policies exist to redistribute income towards poorer households. For example, Manning (2016) argues that minimum wage policies can protect the income from low-wage jobs without an increased risk of job loss.[12] Alternatively, income security for low-wage workers can be organized through welfare-to-work programmes that reduce

[12] Moreover, Cahuc *et al.* (2017) show that hiring credits for minimum wage workers in France during the period 2008–9 significantly increased their employment.

the risk of poverty while incentivizing individuals to do paid work, such as the Earned Income Tax Credit (EITC) in the US or the New Deal in the UK. Many Continental European countries have followed these programmes in different formats and with varying scope since the mid-1990s, but Daguerre and Taylor-Gooby (2004) argue that considerable room remains for further improvements and increases in scope.[13]

### (iv) 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 households more broadly). One good starting point to do this would be for policy-makers to invest in practice-based testing of worker interactions with automated systems such as online job platforms.[14] Based on this information, specific applications, such as online labour markets, can be regulated to better protect and help workers making use of them.

## IV. Conclusions

Technological advances are transforming our labour markets. The hypothesis of routine-biased technological change (RBTC) assumes that digital capital can directly substitute for human labour doing middling routine tasks, leading to an excess supply of medium-skilled workers. These displaced medium-skilled workers have to find jobs with different task requirements both up and down the job complexity ladder, resulting in economy-wide job polarization. In sum, today's labour markets are characterized by a complex interplay between worker skills and digital capital in doing certain tasks, by consequent changes in worker mobility towards jobs requiring different competencies,

[13] Yet another income policy that is often discussed in the popular debate is a guaranteed basic income for each household. There are several experiments with basic income schemes under way, both in Europe and outside it. Although it is unclear whether these programmes, lacking a work incentive, can ultimately be successful.

[14] 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.

and by an economy-wide process of job polarization with winners and losers from ongoing digital progress.

Based on these insights, several relevant policy domains can be identified. A first policy challenge is higher investment in STEM education but also in non-routine social, motivational, and interaction skills that will remain difficult to automate in the near future. Importantly, these non-routine skills exist across many different occupations requiring different levels of education, including a growing number of low-paid service jobs mainly done by unskilled workers. Other policy domains are labour market and income redistribution policies to ensure that the benefits of the Digital Revolution are broadly shared. Specific policies focus on labour market intermediation to assist workers during job transitions; better social security protection for a growing number of workers with non-standard arrangements in low-paid jobs; minimum wages; and welfare-to-work policies. Finally, innovation policies can help in creating technologies that are complementary to worker skills and that help mitigate the impact of technological change on economy-wide inequality. As such, the fundamental threat to future prosperity is not technology *per se*, but its misgovernance.

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