Humans versus Machines: An Overview of Research on the Effects of Automation of Work

Didem Özkiziltan

Anke Hassel

Hertie School of Governance

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Abstract

Digital automation has pervaded many areas of our daily activities, with serious repercussions for social, economic and political systems. Automation's ever-enhancing capability to transform human lives has spawned a wide body of scholarly research, with inputs from social and economic sciences, engineering and technology. This paper[1] provides a brief overview of the main arguments put forward by the researchers, particularly in labour economics, on the subject of digital automation, with a special focus on Germany. Such debates revolve around the impact of automation on the number of jobs performed by human labour and the restructuring of labour markets under the influence of automation. The overview starts with a short discussion about the meaning of digital automation. It then outlines the debates of how technology distributes work between humans and machines from the viewpoint of skill-biased technological change and routine-biased technological change research. This is followed by a summary of the way digital technologies have been restructuring the world of work.

The overview concludes by pointing out research gaps that are particularly relevant in the German context. It emphasizes that a new research agenda should incorporate the role of existing education and training regimes (VET), in particular in light of employment polarisation and the shrinking employment segment of jobs with mid-level pay and skills. Moreover, there is a lack of research that considers the insights of industrial sociology with regard to the renegotiation of work organisation in the process of automation. In particular, the role of institutional factors, such as workers' representatives, in the form of trade unions or works councils, has largely been neglected by studies on labour economics. Finally, there should be more attention paid to the differentiated effects of automation on specific socio-economic groups, such as women and men, but also between different generations.

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Content

1. Introduction

Intelligent machines, such as computers, smart devices and robots, make our everyday lives easier. We can set our robot vacuum cleaner to clean our homes. Our smart speakers dim the lights, while our fridge orders fresh food online. Yet this is only one part of the story, as the capability of machines to carry out some tasks for us has been transforming the world of work. Indeed, intelligent machines, while taking over a lot of the work performed in less labour-intensive industries, services and agriculture, they are making work less dangerous, faster, more precise and more flexible, just as they have been designed to do. For instance, robotic surgery augment the competence of surgeons; automatic milking systems replace workers in dairy farms; scan, pay and go technology reduces the number of workers in the retail sector; surveillance robots assist soldiers in their surveillance and security missions; autopilot technology carries out most of the work for the pilots once commercial passenger airplanes are in the air. In short, machines have pervaded all aspects of everyday life, automating many tasks previously done by manual labour.

In the scholarly literature, the use of machines in economic activities is studied under the title of automation. The automation of work is generally understood as the replacement of human labour input with that of machines or, in other words, with capital (Bessen, 2016; Eurofound, 2017; Acemoglu and Restrepo, 2019). This is not a new development, for machines have been replacing human labour throughout the past two centuries, since their initial deployment in agriculture and manufacturing. What distinguishes automation today from previous periods is its use of digital technologies, which was made possible with the invention of the microprocessor during the early 1970s. Thanks to the microprocessor, mechanical and analogue technologies became less relevant and the digital revolution has unravelled at an increasing pace with reliable network connections, big data analytics, algorithmic decision-making and digital sensors at its core. Digital tools have facilitated a further and speedier automation of previously labour-intensive work, especially in developed economies, with serious repercussions on their social, economic and political systems (Brynjolffson and McAfee, 2016; Eurofound, 2017; Goos *et al.*, 2019).

Automation is a multidisciplinary subject, with input from social and economic sciences, engineering and technology. This paper gives an overview of the main debates, particularly by labour economists, with the aim of identifying research gaps and open questions. In these scholarly discussions, automation is commonly used as an umbrella concept to include

various advanced technologies, such as computers, advanced robotics and artificial intelligence. Despite these various digital technologies are also being scrutinised separately in specialist literature, their joint impacts on the world of work spawned two main lines of scholarly discussions in labour economics: first, the impact of automation on employment and second, the restructuring of labour markets under the influence of automation. These topics are investigated below.

2. Human vs. Machine: Will human labour become obsolete?

In the public debate, the argument concerning the impact of automation on the number of jobs available to human labour has caught widespread attention. The scholarly literature scrutinises this issue by utilising two different methodological approaches: skill-biased technological change (SBTC) and routine-biased technological change (RBTC). Both SBTC and RBTC are mainstream methodologies and their utilisation yields different results and arguments. Despite their marked differences, both approaches consider technology to be the key factor for the shifts in employment structure across the developed economies. Thanks to the introduction of new technologies, as both accounts purport, demand for high-skilled labour has increased, as these advancements complement the skills and increase the productivity of highly-skilled, highly-educated professionals. These technologies, however, have decreased the demand for lower-skilled, less-educated labour, as the tasks performed by this group of workers are more susceptible to being replaced by machines. The arguments pursued by the SBTC and RBTC take on divergent paths in their explanations as to which lower-level skill groups are affected; that is to say, those in the middle of the wage distribution vs. those at the bottom level are more likely to lose their jobs to the technological advancements. The SBTC and RBTC literatures are briefly overviewed below.

2.1. Skill-Biased Technological Change

The SBTC literature is pioneered by a group of authors including Bound and Johnson (1992); Katz and Murphy (1992); Berman *et al.* (1994) and Machin and Van Reenen (1998). Three main assumptions underlie this approach. First, automation is skill-biased, thus, it substitutes low-skilled and complements high-skilled workers. Second, technological development has skill upgrading effect, thus, it increases labour demand for high-skilled workers relative to lower-skilled ones. Third, technological change raises productivity, resulting in higher wages

for both high and low-skilled workers (Arntz *et al.*, 2016b). Those utilising the SBTC method in their research investigate the relationship between technical change, skills and wages mainly by analysing population census data. The findings of such research have proved highly successful in explaining some important changes, such as the growing relative demand for university graduates as well as the increase in their wages during the 1970s and 80s (Acemoglu and Autor, 2011).

The SBTC hypothesis, despite being highly capable of measuring the supply and demand for skills in developed economies, came with significant shortcomings. First, as was calculated by Acemoglu and Autor (2011), in the three decades since the 1980s, wage inequality has increased between high-skilled, high-educated workers and low-skilled, low-educated workers. According to the authors, a major factor causing this gap in earnings has been the sharp decline in the wages of the low-educated workers, rather than the rising wages of the highly-educated. Nevertheless, the SBTC could not explain the rising wage inequality between education groups that became visible in the 1980s (Acemoglu and Autor, 2011). Second, SBTC's argument was based on two skill groups: high-skilled (university graduates) and low-skilled (high school graduates). Thus, it was unable to clarify the decreasing relative demand for middle-paid workers relative to low and high-paid workers that could be seen in labour markets from the late 1980s onwards (Acemoglu and Autor, 2011; Arntz *et al.*, 2016b). Third, it made no distinction between skills and tasks, thus it ignored the fact that skills are assigned to tasks, and tasks can be re-bundled in response to fluctuations in labour market conditions and technology (Acemoglu and Autor, 2011; Autor and Handel, 2013; Eurofound, 2016). Fourth, according to Acemoglu (2003), it interpreted technological development to include new techniques and machines, the changing organisation of production and labour markets, as well as consumer preferences. Thus, as Arntz *et al.*, (2016b) pointed out, it could not precisely assess the role of automation on the changing nature of work. As a consequence of its drawbacks, the SBTC approach became unable to account for the changing employment trends starting from the late 1980s. Thus, the labour economists increasingly turned to the RBTC hypothesis, which is the subject of the next section.

2.2. Routine-Biased Technological Change

The RBTC approach originated from that of SBTC, with the assertion that the substitutability of a job is determined by the number of routine tasks it includes, rather than the skill level it necessitates. By distinguishing between routine, nonroutine as well as manual and cognitive tasks, the RBTC hypothesis builds on a task-based framework originally developed by Autor *et al.* (2003). Unlike the SBTC approach, the RBTC hypothesis interprets technological development as being much narrower, by highlighting machines' increasing ability to undertake routine tasks (Arntz *et al.*, 2016b). Since its initial formulation by Autor *et al.* (2003), the 'task-based framework', or in other words the RBTC approach, was adopted by a large group of authors. Some of these scholars have investigated changes that have occurred in the task-composition of jobs in advanced economies (Autor *et al.*, 2006; Spitz-Oener, 2006; Goos *et al.*, 2009; Akcomak *et al.*, 2013; Autor and Handel, 2013; Goos *et al.*, 2014; Eurofound, 2016; Hardy *et al.*, 2018; Bisello *et al.*, 2019), while others have utilised this approach to predict how many jobs will be replaced by automation in the near future (Frey and Osborne, 2013; Bowles, 2014; Brzeski and Burk, 2015; Arntz *et al.*, 2016a; Nedelkoska and Quintini, 2018).The main assumptions of the RBTC literature are overviewed below.

2.2.1. Machines, Tasks and Jobs: The RBTC approached explained

The original task-based framework, developed by Autor *et al.* (2003), holds four main assumptions: First, tasks and skills are two different variables. Task, as a concept, denotes a unit of activity performed at work and it produces output. The concept of skill, on the other hand, addresses the human capabilities required to fulfil a task. Building on this differentiation, the RBTC approach takes tasks performed at work as its main focus and analyses them along the routine and nonroutine axis. Second, according to the proponents of the RBTC framework, any task can be performed by machines as well as by workers, depending on technological advancements and the cost of computerisation relative to human labour.

Third, at least currently, automation tends to replace routine tasks and complements nonroutine tasks. Routine tasks follow a well-defined practice in a way to be codified and performed automatically based on algorithms. These can be performed manually or cognitively and are often included in middle-paid, middle-skilled jobs such as bookkeeping, clerical work or production jobs. Nonroutine tasks, on the other hand, are related to problem-

solving and complex communication activities. They can be manually or cognitively performed. Manual nonroutine tasks are difficult to be replaced with machines for these require adaptability, visual and language skills as well as personal interactions. These jobs are prevalent in low-paid service occupations, such as catering, cleaning, janitorial work, health, child and old-age care and security services. Cognitive nonroutine tasks, also known as abstract tasks, on the other hand, involve problem-solving, intuition, creativity and persuasion. So far, these skills cannot be achieved by computers. They are considered to complement computers' tasks and these skills can be augmented by computers. Typically, professional, technical and managerial occupations, such as medicine, engineering, design, science, law and marketing, fall into this category (Autor *et al.*, 2003; Autor and Price, 2013; Arntz *et al.*, 2016b; Eurofound, 2016).

Fourth, according to the RBTC hypothesis, as the use of computers at work has increased, the demand for medium-paid workers performing routine tasks has decreased. Computerisation has also increased the demand for and the productivity of workers performing nonroutine tasks that are complementary to the automated tasks (Autor *et al.*, 2003). Hence, the polarisation of employment became visible in the labour markets of the advanced economies starting from the mid-1980s. In the RBTC literature, employment polarisation addresses a hollowing-out process in job markets, where a decrease in the share of routine-intensive, middle-paid, middle-skilled jobs is accompanied by growing shares of nonroutine, intensive, highly-paid, highly-skilled jobs as well as by nonroutine, intensive, low-paid, low-skilled jobs. The job polarisation argument holds that as a job requires higher human skills (visual, social, emotional, creative etc.), nonroutine tasks (interpersonal interaction, flexibility, adaptability, problem-solving etc.) and higher educational attainment, its risk of automation decreases (Autor *et al.*, 2003; Arntz *et al.*, 2016a; MGI, 2017; Nedelkoska and Quintini, 2018).

The RBTC approach offers clear advantages for explaining the impacts of recent technological developments on the labour markets in advanced economies, compared to the SBTC hypothesis. Its analytical power in addressing changes in job task content and shifts in demand, favouring more educated labour and the polarisation of skill requirements in labour markets, have been widely acknowledged by scholars. However, the RBTC framework still suffers from a number of drawbacks.

First, the repercussions of RBTC on employment appear to be more pronounced in the jobs that include more cognitive routine tasks, the performing of which requires individuals to pursue years of education, as in the case of bookkeeping (Feng and Graetz, 2018). Thus, for some, the RBTC is more applicable to the labour-demand effect of computerisation rather than that of industrial robots (Arntz *et al.*, 2016b). The impact of industrial robots on labour markets, instead, is argued to be skill-biased, as they replace low-skilled labour relative to middle and highly-skilled workers (Arntz *et al.*, 2016b; Graetz and Michaels, 2018).

Second, according to some authors, the RBTC, by assuming that tasks can be equally performed by computers and human labour, downplays the advantage of humans over machines in the production process. Indeed, human labour is considered to be flexible and adaptable, able to work in teams and capable of bringing its different strengths to the forefront in accordance with changing circumstances (Deming, 2015; Eurofound, 2016). "Such nonroutine interaction is at the heart of the human advantage over machines", states Deming (2015: 29), for "computers are still very poor at simulating human interaction" (p. 28). Similarly, in Eurofound's (2016: 29-30) account, "at least, until a proper artificial intelligence comes into existence … even the most advanced industrial robots can be understood as being very sophisticated tools: their main effect is to substantially increase the productivity of the few remaining industrial workers."

The third drawback of the RBTC approach is related to the difficulties in measuring the task content. For instance, the robot density indicator, which is widely used by researchers to measure the proportion of tasks handled by robots, needs to be cautiously handled, for, according to Krzywdzinski (2020), despite the fact that the robot density has tripled in the automotive industry since the 1990s, the levels of automation in this industry have remained largely the same. Thus, on the one hand, there is a lack of dedicated data source for sufficiently measuring the changes in the task content of jobs, rendering it more difficult to explain and compare the ways automation has historically impacted the task composition of jobs within and across the developed economies (Eurofound, 2016; Bisello *et al.*, 2019). On the other hand, there is no consensus on how the concept of 'routine tasks' should be operationalised, creating inconsistent and divergent methodologies across the literature (Dengler *et al.*, 2014; Matthes *et al.*, 2014; Fernández-Macías and Hurley, 2016).

Fourth, it is postulated that RBTC, on its own, cannot explain the pattern of job growth across the developed market economies that has become more visible since the mid-1980s. Some

authors draw attention to the economic and political mechanisms that have been at work concurrently with the technological changes to bring a more comprehensive explanation to the transformation of labour markets. Economic mechanisms are related to the cost-effective solutions developed by business. It is argued that technological developments have made it easier for companies to adopt more flexible forms of organisation (Goos *et al.*, 2019), which in turn have increased the offshoring (Akcomak *et al.*, 2013; Goos *et al.*, 2014) and outsourcing (Bessen, 2016; Goos *et al.*, 2019) of routine tasks. As a result, tasks involved in occupations are reorganised and re-bundled in a way to exclude routine tasks from many of the previously routine-intensive jobs, changing the skill-demands – either downwards or upwards – in the labour markets of advanced market economies.

Political mechanisms, on the other hand, are related to the country-specific policies and contexts that can transform the impacts of flexible forms of organisation and technological advancements on occupational structures. This interpretation builds on Eurofound's (2014; 2015; 2016) recurrent finding that, in the presence of increasing automation, while some European countries have been experiencing job polarisation, others' experiences have centred around job upgrading. Thus, according to this view, the noteworthy duality in the ways that occupations have changed across European countries is embedded in institutional contexts, with a political implication that "there is no inescapable trend in occupational developments" (Fernández-Macías, 2015). The discussion in the RBTC literature over the impact of technology on the number of jobs available to human labour is scrutinised next.

2.2.2. Employment in times of automation

The replacement of human labour by machines is an ongoing debate in RBTC literature. So far, scholars have mainly contributed to this discussion with two different approaches: First, according to one group of scholars, machines are increasingly able to master human manual and cognitive skills, which would render humans obsolete in future labour markets (Brynjolffson and McAfee, 2011; Frey and Osborne, 2013; Brynjolffson and McAfee, 2016). This argument is spearheaded by Frey and Osborne (2013) and builds on Autor *et al.*'s (2003) task model with the main assumption that automation replaces routine tasks. Furthermore, Frey and Osborne (2013), (hereafter, FO) claimed that, except for the occupations requiring use of 'creative intelligence', 'social intelligence' and 'perception and manipulation tasks', namely 'three engineering bottlenecks', the automation of almost any task is technologically achievable, as long as adequate data are collected for pattern recognition. To categorise the

automatability of occupations, FO utilised the US O*NET database from 2010 that gathers data on the task content of occupations in the country. Combining data on 702 occupations, FO estimated that 47 % of total US employment faces the high risk of disappearing by 2033. In the following years, researchers applied FO's approach to various regional and country cases. Utilising ILO data, which is based on the 2012 EU Labour Force Survey, Bowles (2014) estimated that between 45 and 60 % of the jobs in Europe are at a high risk of disappearing within the next 20 years. Similarly, using the data from the Classification of Occupations (KldB) from 2010, provided by the Federal Employment Agency, Brzeski and Burk (2015) found that 59 % of jobs are at a high risk of being replaced by automation in Germany by 2033.

FO's approach has intensified the already-heated debate on whether advancing technologies have the power to make human labour redundant (Autor, 2015; Arntz *et al.*, 2016a; Brynjolffson and McAfee, 2016; Marr, 2017; MGI, 2017; Nedelkoska and Quintini, 2018). Some have argued that the O*NET dataset, utilised by FO, has intrinsic problems, in that its task content information rests on the valuation of researchers and experts of the labour market and workers in a particular occupation, rather than providing an individual task composition of each job/occupation across the labour market (Autor and Handel, 2013; Arntz *et al.*, 2016a; Nedelkoska and Quintini, 2018). Furthermore, according to Krzywdzinski (2020), the physical and technical circumstances of automation need to be examined at the level of entire manufacturing processes, rather than at the level of individual professions or tasks.

Addressing this gap, and by carefully building on and improving FO's task-based approach, Arntz *et al.* (2016a) re-estimated the proportion of jobs that are at risk from automation for 21 OECD countries, including the US. In their analysis, the authors have used OECD's 2012 PIACC database (Programme for the International Assessment of Adult Competencies) that is based on individual survey data, providing a comprehensive list of tasks workers actually carry out at their workplace. Arntz *et al.* (2016a) also relaxed one key assumption of FO and thus argued that only certain tasks can be replaced by automation rather than entire occupations, because most occupations include tasks that are difficult to automate. They also pointed out that, even within the same occupations, tasks are bundled differently both across workplaces as well as countries, making it difficult to generalise the risk related to the replacement of human labour by machines. As a result, Arntz *et al.* (2016a) observed that, on average, 9 % of jobs are highly automatable across the 21 OECD countries. They have found

discrepancies across OECD countries, with the share of highly-automatable jobs being 6 % in Korea, 12 % in Germany and 9 % in the US.

By closely following the FO's approach, and by utilising the above-mentioned PIACC database for the years 2011/2012 and 2014/2015, a similar study was also conducted by Nedelkoska and Quintini (2018) with the aim of analysing the risk of job losses through automation in 32 OECD countries. The authors calculated that around 14% of jobs in OECD countries are highly automatable, affecting up to over 66 million workers in the 32 countries covered by the study. Nedelkoska and Quintini (2018) ascertained that the actual risk of automation varies significantly across countries, from 33% of all jobs in Slovakia, to 18% in Germany and 6% in Norway. In the German context, a recent study by Dengler and Matthes (2018) also confirmed that the automation potential of jobs is much lower than that calculated by those utilising FO's methodology. Using data by the German Federal Employment Agency (BERUFNET database), they observed that 25 % of workers were employed in an occupation with a high risk of automation in 2016, with the risk being the highest in the transport and logistics professions.

In the debate on the replacement of human labour by automation, a second group of authors focuses on the polarisation of employment. Pioneered by Autor *et al.* (2003), this group of authors also utilise a task-based approach in their research, leading to comparably similar and complementary results for different country cases. For instance, based on data from the Dictionary of Occupational Titles (DOT), over the almost four-decade period from 1960 to 1998, Autor *et al.* (2003) found that computerisation has reduced the use of routine manual and routine cognitive tasks while increasing the use of nonroutine cognitive tasks within industries, occupations and education groups in the US. Goos *et al.* (2014) analysed the harmonised, individual-level European Union Labour Force Survey (ELFS) for the 1993–2010 period, Eurofound (2016) made use of the European Working Conditions Survey (EWCS) and the OECD's PIAAC data for the years 2011-2015, and Bisello *et al.* (2019) used EWCS data from 1995 to 2015. All ascertained that routine tasks, which are repetitive and/or require physical strength are on the decrease, while nonroutine tasks relating to social, literary and ICT (information and communications technology) skills are on the increase across European countries.

Similarly, employing data from the "Qualification and Career Survey", which provides individual-level data for the 1979-1999 period, regarding changing occupational skill

requirements in West Germany, Spitz-Oener (2006) showed that the task composition of occupations in West Germany have significantly changed with the advancement of automation, resulting in a hollowing-out of the middle of the job market. More precisely, in her analysis, Spitz-Oener (2006) unearthed a considerable decline in cognitive and manual routine tasks, that used to be performed by mid-skilled labour, and a noticeable increase in analytical and interactive activities, that require highly-educated, highly-skilled workers, in West Germany. Following in Spitz-Oener's (2006) footsteps, a body of recent research also confirmed a remarkable and continuous change in employment, away from routine, middle-skilled occupations and towards an increased automation of work in Germany (Fernández-Macías, 2015; Consoli and Roy, 2017; Bachmann *et al.*, 2019).

Some recent studies also brought into the open regional and individual effects of employment polarisation in Germany. Regarding the former, Consoli and Roy (2017) ascertained that the increase in imports in goods and services contributed to the decline in the number of routine jobs in West Germany. They draw their data from the Qualification and Career Survey, the Sample of Integrated Labour Market Biographies, the vocational education reports from the Federal Institute for Vocational Education and Training and the OECD's sector-level trade data. Consoli and Roy (2017) also observed that in the regional employment districts of West Germany, where the share of routine occupations was initially high, a higher adoption of ICT and a larger decline in the share of routine jobs occurred between the years 1979-2012. What is more, according to the authors, in recent decades, Germany's apprenticeship system reinforced the trend towards occupational upgrading, leading to growing numbers of managerial and professional occupations that exceeded the number of new jobs in the country's service sector .

When it comes to the impact of automation on individuals in Germany, Bachmann *et al.* (2019), by using data from the Integrated Labour Market Biographies provided by the Institute for Employment Research, followed adjustment processes of individual workers in relation to the RBTC for the 1975–2014 period. The authors discovered an 'employment penalty to routineness of work', threatening those working in routine jobs with a higher risk of facing unemployment in both one year (short term) and five years (medium term) of employment. However, the authors also revealed that the disadvantage of being in a routine job is partly offset by higher job finding rates of workers previously employed in jobs with a higher routine-task content. By employing register data from the Federal Employment

Agency of Germany for the years 1985-2010, another individual-level study was conducted by Janssen and Mohrenweiser (2018), who investigated the way incumbent workers in the German metal working industry adjust their careers in response to the increasing labour supply of new graduates with more advanced IT skills. The authors observed that, during the periods of fast technological transformation, despite incumbents with outdated skills being more likely to lose their jobs to newly graduated entrants with up-to-date IT skills, they do not experience much unemployment, as they change their occupations within that industry or switch to service sector jobs.

The body of research focusing on country-specific impacts of automation on employment is not limited to Germany. For instance, Akcomak *et al.* (2013) utilised data of the British Labour Force Surveys (LFS) and Skills Surveys for 1997 and 2006, observing that employment in medium-skilled, medium-paid occupations has been in decline, compared to highly-skilled as well as low-skilled occupations in the UK. Using the EU's Individual Labour Force Survey data on the basis of occupations between 1998 and 2015, Hardy *et al.* (2018) analysed the post-transition European countries, revealing that all the Central and Eastern European countries (CEECs) witnessed an increase in nonroutine cognitive tasks and a decrease in manual tasks. However, in their analysis, the authors also observed that routine cognitive tasks increased in seven CEECs while declining in three, concluding that the varied changes in routine cognitive tasks can be ascribed to diverse forms of structural change in the CEECs.

The employment polarisation argument, besides providing a detailed understanding of the jobs being lost to and gained thanks to automation, offers an alternative interpretation on the number of jobs to be replaced by robots in the future. According to this strand of the literature, occupations consist of various tasks bundled with each other, and it is the tasks that are susceptible to automation rather than entire occupations (Arntz *et al.*, 2016b; Bisello and Fernández-Macías, 2016; Eurofound, 2018). This explanation further purports that, since automation has so far brought about a small positive effect on aggregate employment, it is highly likely that this trend will continue (Arntz *et al.*, 2016a; Goos *et al.*, 2019; OECD, 2019b). According to this body of literature, the future of work is more about **changing structure of work** that includes, yet is not limited to, the updating/upgrading of skills and the increasing use of nonstandard forms of work and employment (Arntz *et al.*, 2016b; MGI,

2017; OECD, 2019b). An overview of the explanation, provided by the RBTC literature, as to why automation is unlikely to render human labour obsolete is the subject of the next section.

3. Humans competing with machines: The dynamics explained

Despite the somewhat bleak interpretation of the scholarly debate pioneered by Frey and Osborne (2013) on the future of work, the available evidence suggests that automation has so far created more new jobs than it has destroyed, rendering humans able to compete with machines rather than against them (Arntz *et al.*, 2016b; Bessen, 2016; Gregory *et al.*, 2016; Autor and Salomons, 2018; Goos *et al.*, 2019; OECD, 2019b). For instance, according to Gregory *et al.* (2016), out of a total of 23 million new job openings, 11.6 million of these were made possible thanks to RBTC across 27 European countries during the period 1999-2010. Gregory *et al.* (2016) also note that this increase has occurred in an environment where, despite 9.6 million jobs being replaced by automation, 21 million new jobs were created thanks to increasing product demand and spill-over effects. Similarly, Autor and Salomons (2018) have found that technological advancements, despite having decreased labour's share in industries where they were directly used, have boosted total employment levels in the OECD countries since 1970. Indeed, for instance, in the case of Germany, as was calculated by Dauth *et al.* (2017), in the period 1994-2014, despite every robot having replaced two workers in the manufacturing sector, adding up to approximately 275,000 jobs, almost an equal number of new jobs were created in the service sector, thus fully compensating these job losses.

How does RBTC increase aggregate employment levels across developed economies, despite replacing routine tasks? In other words, how do humans, at least as of now, compete with machines rather than against them? In explaining this puzzle, some authors point to a number of mechanisms counterbalancing each other in labour markets (Autor, 2015; Gregory *et al.*, 2016; Acemoglu and Restrepo, 2017; Autor and Salomons, 2018; Goos *et al.*, 2019). In one of their recent studies, Acemoglu and Restrepo (2019) have presented a comprehensive framework for explaining these mechanisms, placing emphasis on the impacts of automation on tasks, productivity and work. According to this framework, automation puts three main mechanisms to work: First is automation's *displacement effect,* addressing the direct replacement of human labour by machines. Second is the *productivity effect*, denoting a growing labour demand for non-automated tasks (i.e. childcare, personal care, catering,

sales), thanks to the decreasing price of automated tasks boosting the economy. Third is the *reinstatement effect*, indicating the creation of new tasks, in which labour has a comparative advantage (i.e. designing, operating and maintaining new machines and software). According to Acemoglu and Restrepo (2019: 27), scrutinising the changes in labour markets under the optic of this framework indicates that "neither the claims that the end of human work is imminent nor the presumption that technological change will always and everywhere be favourable to labour."

Furthermore, an overview of the literature suggests that there are some other forces at work operating simultaneously with the above-mentioned three adjusting mechanisms of automation. First, as many authors indicate, various economic, social and political issues create obstacles in the everyday use of new technologies. For instance, according to Acemoglu and Restrepo (2018), despite the theoretical possibility that all tasks can be automated, in real life, tasks are automated when their allocation to machines generates more profit. What is more, according to the authors, automation, by bringing down the cost of labour in the tasks that are easy to perform, restrains its own speed of diffusion, as this way it 'generat[es] a self-correcting force toward stability' (Acemoglu and Restrepo 2018: 1526). Another economic issue appears to be the additional investment expenses, as, according to Brynjolfsson *et al.* (2019), the adoption of new technologies requires organisational restructuring, new skills and new employees, all of which incur extra costs for companies. When it comes to social and political issues, for example, minimum wage mechanisms, collective bargaining and other wage-setting institutions, as were highlighted by Arntz *et al.* (2019), play an important role in companies' decisions to automate tasks, for these might exert a noticeable impact on labour costs. Furthermore, the utilisation of some new technologies, as in the case of driverless cars, require the consideration of various ethical and legal dilemmas that are yet to be resolved (Bonnefon et al., 2016; Lee, 2017). It is also pointed out that, even if some tasks are fully automatable, for instance: music production or artisan baking, people might prefer human labour over machines in the performance of some tasks, rendering humans capable of competing with, rather than against, machines (Pratt, 2015).

Second, it is argued that an introduction of new technologies to the workplace tends to change the **task composition of jobs** rather than replacing entire occupations (Spitz-Oener, 2006; Autor, 2015; Arntz *et al.*, 2016b; Bessen, 2016; Arntz *et al.* 2019). Such alteration in

task composition, according to Arntz *et al.* (2017; 2019), renders those working in occupations under a high risk of automation able to undertake tasks that are difficult to automate. Indeed, according to Dauth *et al.* (2017), in the 1994-2019 period, robot-exposed workers in Germany were more likely to keep their existing jobs with a possible change in job task composition. Similarly, Spitz-Oener (2006) found that in the period covering the years 1979-1999, more than 99 % of workers in West Germany adjusted their tasks in accordance with changing technology, and fewer than 1 % of workers lost their jobs directly because their labour was replaced by machines.

Third, as was indicated by MIT (2019), many developed economies are currently experiencing a remarkable **demographic transformation,** triggered by factors such as sluggish rates of labour force growth, plummeting ratios of workers to retirees and stricter immigration policies. Thus, according to MIT (2019: 10), "over the next two decades industrialized countries will be grappling with more job openings than able-bodied adults to fill them." In the same way, as the scholarly evidence supports the claim that humans are racing with machines, an increasing number of studies confirms that work is being re-organised as new technologies are being introduced to the workplace. This subject will be reviewed next.

4. Automation: The restructuring of work

Regardless of the fact that SBTC and RBTC approaches build on different perspectives and yield different results, within the automation literature authors commonly argue that technological developments **upgrade** the skill requirements for occupations (Brynjolffson and McAfee, 2016; Eurofound, 2017; MGI, 2017; Goos *et al.*, 2019). The upgraded skills, as the argument purports, are made up of a novel combination of hard and soft skills. Hard skills are comprised of those related to ICT, such as a command of various operating systems and office software, basic coding and graphic design. Soft skills are the cognitive nonroutine ones, including interpersonal interaction, social intelligence, entrepreneurial thinking, creativity, flexibility, adaptability and problem solving (Eurofound, 2017). Research evidence also indicates that new technologies increasingly facilitate different work arrangements, such as job offshoring, outsourcing, use of home offices, platforms and crowdsourcing (Akcomak *et al.*, 2013; Goos *et al.*, 2014; Eurofound and ILO, 2017; ILO, 2018). These changes in skill

requirements and work arrangements, in turn, are considered to bear some serious consequences on the structure of work and employment.

First, as the skill requirements of jobs change, middle and low-skilled, middle and low-educated workers come out as the **losers of automation,** for they are placed under high pressure to embrace the changing nature of work by taking occupational training to gain new skills and/or upgrade the ones they have. Yet research evidence shows that these are the ones who have difficulties in accessing these upgrading opportunities (Bassanini and Ok, 2004; Albert *et al.*, 2010). Second, automation, by creating a large group of losers, feeds into the already exacerbated **inequalities** in the world of work. If workers cannot adjust to changes, either their wages fall into a relative decline compared to highly-skilled workers (Cortes, 2016; Dauth *et al.* 2017; Kurer and Gallego, 2019), or they are forced to accept lower-skilled, lower-paying jobs (Autor and Dorn, 2013; Janssen and Mohrenweiser, 2018; Green, 2019). For instance, in the case of Germany, as was observed by Janssen and Mohrenweiser (2018), following the introduction of CNC (Computerized Numerical Control) in the metal working industry, incumbent workers with outdated skills experienced lower wage growth, became less likely to receive promotion at work and more likely to switch their occupation, and had to increasingly accept low-wage service jobs. These jobs, however, often come with less favourable working conditions, little job stability and too long or inadequate working hours, as they are shaped in an environment where increased job offshoring, outsourcing, use of home offices, platforms and crowdsourcing become the order of the day (Green, 2019).

Third, this **rising inequality** in the world of work is likely to affect women, young (OECD, 2019b) and older (Aubert *et al.*, 2006; Autor and Dorn, 2009) workers as well as those without tertiary degrees (Green, 2019; OECD, 2019b), as these are the ones who often find themselves in the position of having to opt for the jobs located on the lower end of the job spectrum. Fourth, as technology advances, previously non-automatable jobs, performed by low-skilled, low-educated workers, are being replaced by machines (Arntz *et al.*, 2016a; Graetz and Michaels, 2018). This, as argued by Arntz *et al.* (2019), renders new technologies increasingly **skill biased** rather than routine biased, putting the jobs of already disadvantaged low-skilled workers at risk of disappearing.

Fifth, it is argued that, even for workers with little risk of losing their jobs, the new world of work poses various challenges. For instance, as the physical boundaries are increasingly disappearing with the use of new technologies, it is claimed that many workers find

themselves working in **isolation,** with little or no prospect of collective representation and solidarity (Eurofound, 2018; Parolin, 2019). What is more, even in highly-skilled jobs, such as managers and professionals, a significant increase in repetitiveness and standardisation has been reported, suggesting that automation facilitates the routinisation of some previously nonroutine cognitive tasks (Bisello *et al.*, 2019).

Sixth, those coworking with robots appear to find themselves in a work environment where they constantly need to acquire new qualifications, and technical and organisational capabilities. As pointed out by Moniz and Krings (2016), this constant need for change occurs mostly because system integrators and robot manufacturers rarely consider the social impact of new technologies on working environments. Yet, perhaps such an awareness on the part of the system designers and producers might provide a partial solution to the human-robot interaction puzzle, for, as was aptly put by Sheridan (2016: 531), "[w]hereas the human race is changing very slowly, computers and robots are evolving at a very rapid pace". The gaps in the automation literature are investigated next.

5. The gaps in the employment polarisation literature

Since Autor *et al.*'s (2003) introduction of the concept of employment polarisation, many labour economists have directed their attention towards understanding how pervasive it is across economic regions (Goos *et al.*, 2014; Eurofound, 2016; Bisello *et al.*, 2019) and in individual countries (Autor *et al.*, 2003; Spitz-Oener, 2006; Goos and Manning, 2007). However, a critical overview of this body of literature suggests that there are still under-researched areas, both in general and in particular in the context of Germany, especially when it comes to the impact of employment polarisation on workers and industrial sectors.

Regarding companies, evidence from existing studies indicates that, in general, the increased intensity of ICT use in companies does not reduce the number of people they employ (Pantea *et al.*, 2014; Biagi and Falk, 2017). What is more, in the particular context of Germany, firms that invest in ICT also invest more in training their workers (Janssen *et al.*, 2018). However, the repercussions of ICT use on workers, both individually and collectively, remains an under-researched topic. For instance, to our knowledge, with the exception of Janssen and Mohrenweiser's (2018) study, no other micro-level research has been conducted on the strategies of employees for dealing with their out-of-date skills following the firms' adoption

of new ICT. That is, incumbent middle-skilled workers in the German metal working industry respond to the increasing competition of more technologically-advanced skilled workers by switching to other occupations and sectors (Janssen and Mohrenweiser, 2018). Similarly, studies focusing on different groups of workers are also highly limited, despite employment polarisation's marked effect on women (Autor *et al.*, 2003; Cortes *et al.*, 2016; Eurofound, 2016; Green, 2019), younger (OECD, 2019b) and older workers (Aubert et al., 2006; Autor and Dorn, 2009) have been acknowledged in the scholarly literature.

Amongst different groups of workers, women seem to have attracted a degree of scholarly attention. The available studies on female workers in general address a visible decline across advanced market economies in the number of women working in middle-skilled occupations, with their employment shift displaying both upward and downward trends (Eurofound, 2016; Cerina *et al.*, 2017; Green, 2019). In the context of Germany, the pioneering research applying a gender perspective on employment polarisation was conducted by Black and Spitz-Oener (2010). In their study, the authors purported that, from the period 1979-1999, the job task content for women has noticeably shifted from routine to nonroutine analytic and interactive tasks. The findings of Black and Spitz-Oener (2010) were confirmed and extended to the 1975-2010 period by the research of Lehmer and Matthes (2015). The authors, in the same way as Black and Spitz-Oener (2010), concluded that the tendency towards technology-driven polarisation in the German labour market has been larger for women than for men.

Nevertheless, despite the availability of some studies on **gender effects** of employment polarisation, more research needs to be conducted on groups of workers that are vulnerable to workplace discrimination in order to bring a more comprehensive understanding to the employment polarisation in general, and in a German country context in particular. In our view, current empirical approaches employed across the extant literature, despite being highly useful in bringing to light digital automation's economic consequences, do little when it comes to unpacking its socioeconomic repercussions. Indeed, empirically, the main arguments addressed by scholars revolve around changes in job task content and employment shifts towards upper or lower skill levels and wage scales, leaving out issues such as the ways women cope with the looming changes in their careers, the support mechanisms available to them and the consequences of their decisions.

Workers' voice comes out as another topic that remains significantly under-researched in the employment polarisation literature. A pioneering cross-country study on this topic has been

conducted by Parolin (2019), where he scrutinised the ways trade unions and collective bargaining coverage curb the effects of RBTC on the wages of high-routine occupations across 16 OECD member states from the 1980s onward. His findings reveal that, while bargaining coverage is more significant for the wage growth of high-routine occupations relative to less routine ones, high-routine occupations lose their bargaining coverage at a more rapid speed than nonroutine ones when collective bargaining coverage at the national level shrinks.

In the German context, workers' voice in the face of digital automation has attracted some scholarly attention since the 1990s, especially from the perspectives of trade unions, regarding the launch and utilisation of technological innovation. This body of literature, however, purports somewhat conflicting arguments on works councils and trade unions. For instance, regarding works councils, findings range from their positive effect on R&D in the case of a not "too high" union density (Schnabel and Wagner, 1994), a positive and modest to strong association between works councils and all forms of innovation (Allen and Funk, 2008) and a positive association between works councils and the utilisation of digital technologies in the case of a high number of workers performing physically demanding job tasks (Genz *et al.*, 2019). When it comes to the effects of trade unions on innovation, Schnabel and Wagner (1994) found no statistically significant negative association at the industry level in Germany, but Allen and Funk (2008) observed a statistically significant negative association between sectoral collective agreements and innovations that threaten the workers' skill sets.

These inconsistencies in the literature, while calling for further inquiry into the topic, also draw attention to the need to broaden the methodological horizons of the ongoing research. Indeed, all the above-cited studies on Germany utilised quantitative methods in their research designs. However, investigating the same issue by employing qualitative research methods can bring plausible explanations as to why such diversity in workers' voice was observed by previous research. For instance, having drawn their empirical results from qualitative interviews with members of the works councils from twelve companies across five industries, Georg *et al.* (2017) ascertained that there are five different types of works councils with different reactions towards innovation. These range from *co-digitalisers* with a high participation in and high awareness of digitalisation processes, to *reactives* with a low participation in and low awareness of transformation processes.

A careful investigation of the employment polarisation literature also reveals that the studies analysing the **employment effects of polarisation on the sectoral level** are significantly limited, both in general and particularly for Germany. Amongst the available research, for instance, the OECD (2016) reports a process of employment reallocation between the sectors as a result of ICT investments. Accordingly, permanent decreases in employment in the manufacturing sector and, to a lesser extent, in the business services, trade, transport and accommodation sectors are compensated by increases in employment in other sectors, especially in culture and recreation and construction over the period 1990-2012. The OECD (2016) study also provides a brief employment polarisation profile of Germany by its sectors. According to the research, in the years following 2007, ICT investments resulted in a 0.03% annual decrease in labour demand in Germany, which became most visible in the manufacturing sector. However, the findings also suggest that such decrease in sectoral employment was partly compensated by an increase in labour demand in other sectors, including agriculture, culture, recreation and other services.

According to Eurofound (2016), on the other hand, while the services sector, particularly the health, professional services, and hotel and restaurant sectors, accounted for nearly all new employment across the EU countries during the period 2011-2015, a marked upskilling trend occurred in the construction and manufacturing sectors, where the number of positions in both sectors grew in highly-paid, top quintile jobs, while declining in middle and lower paying jobs. An upskilling trend in employment was also observed by Graetz and Michaels (2018) across the robot-using manufacturing sectors of 17 advanced industrialised countries, including Germany, between the years 1993-2007. Similarly, Michaels *et al.* (2014) revealed an ICT-based polarisation in 11 advanced industrialised countries, including Germany, in the years between 1980-2004, with the observation of a rapid upgrading of skills, especially in services, such as in finance, telecommunications and business services, and in manufacturing, such as in chemicals and electrical equipment production. More recently, Krzywdzinski (2020) highlighted upskilling trends in the German automotive industry, where the number of engineers and computer scientists are rapidly increasing, while that of blue-collar workers' is declining.

As a result, in order to bring a more comprehensive understanding to the employment restructuring in the labour markets of developed economies, additional, previously under-

researched issues should be addressed. This is particularly true for questions regarding the way workers cope with labour market restructuring:

- Do workers in general, and in particular more vulnerable groups of workers, i.e. women, older and younger employees etc., receive support from their employers during the period of intense technological change in order to update their skill sets?
- If so, how do these different groups of workers utilise vocational training and life-long learning opportunities? Are there differences in different groups of workers as to how they receive and make use of their training prospects?
- What are the reasons behind the workers' decisions to stay in the same firms/sector or to switch to other occupations/sectors when their skills become out-of-date due to the introduction of ICT?

6. Conclusion

Automation, as it is currently discussed by labour economists, is driven by the advanced technologies of our age, such as computers, advanced robotics and artificial intelligence. According to the evidence from the literature, automation is transforming the world of work by changing the tasks required from human labour as well as by restructuring the nature of work.

The literature on the impact of automation on work has made great advances over the last two decades. In particular the move from SBTC to RBTC and the shift of perspectives from skills to tasks have allowed for a more fine-grained analysis of the restructuring of labour markets. Empirically, the main argument addressed by many scholars has moved from the question of how many jobs will be lost to automation to the issue of the restructuring of work and the polarisation of the labour market. It is expected that – depending on available data, the polarisation hypothesis will be further expanded to cover precarious and non-standard forms of work and their utilisation by platform firms and gig workers.

There are a number of open questions, which are particularly relevant in the context of the German labour market. Polarisation trends based on RBTC affect primarily those with mid-level skills in mid-level paid jobs. Germany relies heavily on mid-level skills and invests heavily in apprenticeships (vocational training). Indeed, according to recent OECD (2019a)

research, 58% of adults in Germany have upper secondary or post-secondary non-tertiary education as their highest educational attainment (compared to 44% on average across OECD countries) and only 32% have tertiary education (compared to about 44% as the OECD average). If RBTC correctly assumes that these employment segments are likely to be hit hardest, the German training institutions will have to adapt towards providing skills that allow for upward mobility. Currently the VET system is slow to train in new professions but tends to update existing training schemes (Arntz et al. 2016). Also, life-long learning will become much more important for future generations of workers. More research is needed that specifically focuses on the role of vocational training in the context of employment polarisation.

Secondly, employment polarisation is conceptualized in terms of the changing number of workers in occupations. There is little knowledge as to whether these structural changes occur due to changes in the size of sectors or the emergence of new economic sectors. It is also under-researched as to how the (re)organisation of firms and the role of labour within a firm can influence the trajectory of change. Given the fact that the influence of works councils and trade unions in the German system is still pervasive (though declining), we should expect that co-decision rights and collective agreements shape the trajectory of corporate restructuring due to technological change. Studies in labour economics have, however, rarely connected the role of workers' voice with automation, in contrast to studies in industrial sociology, which are, however, based on case studies and qualitative data (see Briken *et al.*, 2017). It is recommended to engage in research which is based on insights by industrial sociology and to find ways of applying them to existing datasets in order to focus on these questions.

Finally, research on the effects of automation rarely considers the individual characteristics of workers. We do not know yet the ways in which individuals cope with the structural changes when their jobs are affected by automation, whether predominantly female occupations are more affected by automation compared to male or whether young workers have a harder time on the labour market compared to older ones due to technological change. To overcome these shortcomings, a new research agenda should incorporate institutional factors, such as workers' voice and the role of existing training regimes (VET), with the differentiated effects on specific socio-economic groups and the best practices for workers to cope with labour market restructuring.

7. Appendix: Summary of Selected Literature

Autor	Title	Publisher	Data source	Main argument
Acemoglu and Restrepo (2017)	Robots and Jobs: Evidence from US Labor Markets	NBER	International Federation of Robotics	One more robot per thousand workers reduces the employment to population ratio by about 0.18-0.34 % and wages by 0.25-0.5 %.
Acemoglu and Restrepo (2019)	Automation and New Tasks: How Technology Displaces and Reinstates Labor	Journal of Economic Perspectives	• U.S. Bureau of Economic Analysis • Bureau of Labor Statistics	Despite the fact that machines are unlikely to make human labour obsolete in the near future, technological change may not always be in favour of labour.
Arntz *et al.* (2016)	The Risk of Automation for Jobs in OECD Countries: A Comparative Analysis	OECD	OECD's Programme for the International Assessment of Adult Competencies	On average 9 % of jobs are highly automatable across the 21 OECD countries with discrepancies across them.
Autor and Dorn (2013)	The Growth of Low Skill Service Jobs and the Polarization of the U.S. Labor Market	American Economic Review	• Census IPUMS • American Community Survey	Rising employment and wages in service occupations account for a substantial share of aggregate polarisation and growth at the lower end of the US employment and earnings distributions between 1980-2005.
Autor and Salomons (2018)	Is Automation Labor Share–Displacing? Productivity Growth, Employment, and the Labor Share	NBER	EU KLEMS	Technological advancements, despite having decreased labour's share in industries where they were directly used, have

				boosted total employment levels in the OECD countries since 1970.
Autor *et al.* (2003)	The Skill Content of Recent Technological Change: An Empirical Exploration	The Quarterly Journal of Economics	• Dictionary of Occupational Titles • U.S. Census and Current Population Survey	Computerisation is associated with a reduced labour input of routine manual and routine cognitive tasks and an increased labour input of nonroutine cognitive tasks in the US over the period of 1960-1998
Autor *et al.* (2006)	The Polarization of the U.S. Labor Market	NBER	• Current Population Survey • Merged Outgoing Rotation Group	Employment has been polarising into high-wage and low-wage jobs at the expense of middle-wage work in the US since 1980.
Bessen (2016)	How Computer Automation Affects Occupations: Technology, Jobs, and Skills	Boston University	• American Community Survey • US Census	Occupations using computers grow faster, even for highly-routine and mid-wage occupations. Despite this, computer automation is not a significant source of overall job losses, computerized occupations are a substitute for other occupations, shifting employment and requiring new skills.
Bisello *et al.* (2019)	How Computerisation Is Transforming Jobs Evidence from	Eurofound	• European Working Condition Survey • EU-Labour Force Survey	Jobs with more social task content have expanded relative to the rest, despite the number

	Eurofound's European Working Conditions Survey.		• European Jobs monitor data • US O*NET	of social tasks people actually do in their jobs having declined.
Deming (2015)	The Growing Importance of Social Skills in the Labor Market	NBER	National Longitudinal Survey of Youth for 1979 and 1997	The US labour market increasingly rewards social skills. The labour market return to social skills was much greater in the 2000s than in the mid-1980s and 1990s.
Eurofound (2016)	What Do Europeans Do at Work? A Task-Based Analysis: European Jobs Monitor 2016.	Publications Office of the European Union	• European Working Conditions Survey • OECD's Programme for the International Assessment of Adult Competencies	There is a typical path of change in the task profile of countries, with physical, routine and machine-use tasks being in decline, while intellectual, social tasks and ICT use are experiencing a steady growth.
Frey and Osborne (2013)	The Future of Employment: How Susceptible Are Jobs to Computerisation?	Initially published as a working paper by the University of Oxford, in 2017 as an article in Technological Forecasting and Social Change	US O*NET	47 % of total US employment faces a high risk of disappearing by 2033.
Goos *et al.* (2014)	Explaining Job Polarization: Routine-Biased Technological Change and Offshoring	The Quarterly Journal of Economics	Harmonized individual level European Union Labour Force Survey	Job polarization was pervasive across European economies in the period 1993-2010
Graetz and Michaels (2018)	Robots at Work	The Review of Economics and Statistic	International Federation of Robotics	The impact of industrial robots on labour markets, is skill-biased, as they replace low-skilled labour relative to middle and highly-skilled workers

Green (2019)	What Is Happening to Middle Skill Workers	OECD	• Sample of Integrated Labour Market Biographies & German Socio-Economic Panel for Germany, • European Labour Force Survey for EU countries • Current Population Survey (CPS) for the US.	The best predictor of working in middle-skill jobs is the lack of a tertiary degree. Workers without a tertiary degree have been sliding down the job ladder in OECD countries during the last two decades.
Gregory *et al.* (2016)	Racing with or against the Machine? Evidence from Europe	Zentrum für Europäische Wirtschaftsforschung	European Union Labour Force Survey	Out of a total of 23 million new job openings, 11.6 million of these were made possible thanks to RBTC across 27 European countries over the period of 1999-2010.
Hardy *et al.* (2018)	Educational Upgrading, Structural Change and the Task Composition of Jobs Economics of Transition in Europe	Economics of Transition	European Union Labour Force Survey	All the CEE countries witnessed an increase in nonroutine cognitive tasks and a decrease in manual tasks during the 1997-2006 period.
Nedelkoska and Quintini (2018)	Automation, Skills Use and Training	OECD	OECD's Programme for the International Assessment of Adult Competencies data	Around 14% of jobs in 32 OECD countries are highly automatable, affecting over 66 million workers in these countries.
Spitz-Oener (2006)	Technical Change, Job Tasks, and Rising Educational Demands: Looking Outside	Journal of Labor Economics	Qualification and Career Survey for West Germany	The task composition of occupations in West Germany has significantly changed with the advancement of

	the Wage Structure			automation, resulting in a hollowing-out of the middle of the job market.

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