OECD Social, Employment and Migration Working Papers
No. 193

# Structural Transformation in the OECD: Digitalisation, Deindustrialisation and the Future of Work

**Thor Berger,**

**Carl Benedikt Frey**

https://dx.doi.org/10.1787/5jlr068802f7-en

OECD

**Unclassified** **DELSA/ELSA/WD/SEM(2016)19**

Organisation de Coopération et de Développement Économiques
Organisation for Economic Co-operation and Development **26-Sep-2016**

**English - Or. English**

**DIRECTORATE FOR EMPLOYMENT, LABOUR AND SOCIAL AFFAIRS**
**EMPLOYMENT, LABOUR AND SOCIAL AFFAIRS COMMITTEE**

**Cancels & replaces the same document of 23 September 2016**

DELSA/ELSA/WD/SEM(2016)19
**Unclassified**

**OECD SOCIAL, EMPLOYMENT AND MIGRATION WORKING PAPERS No. 193**

# STRUCTURAL TRANSFORMATION IN THE OECD: DIGITALISATION, DEINDUSTRIALISATION AND THE FUTURE OF WORK

*Thor Berger (Oxford Martin Programme on Technology and Employment, Oxford Martin School, University of Oxford and School of Economics and Management, Lund University)*

*Carl Benedikt Frey (Oxford Martin Citi Fellow, Oxford Martin Programme on Technology and Employment, Oxford Martin School, University of Oxford)*

*JEL Codes: E24, J24, J62, O33*

*Keywords: digitalisation, future of work*

*Authorised for publication by Stefano Scarpetta, Director, Directorate of Employment, Labour and Social Affairs*

For further information please contact: Stijn Broecke (stijn.broecke@oecd.org, +33 1 45 24 82 48). All Social, Employment and Migration Working Papers are available on www.oecd.org/els/workingpapers

**JT03401279**

**Complete document available on OLIS in its original format**
***This document and any map included herein are without prejudice to the status of or sovereignty over any territory, to the delimitation of international frontiers and boundaries and to the name of any territory, city or area.***

**English - Or. English**

# OECD SOCIAL, EMPLOYMENT AND MIGRATION WORKING PAPERS

**WWW.OECD.ORG/ELS/WORKINGPAPERS**

OECD Working Papers should not be reported as representing the official views of the OECD or of its member countries. The opinions expressed and arguments employed are those of the author(s).

Working Papers describe preliminary results or research in progress by the author(s) and are published to stimulate discussion on a broad range of issues on which the OECD works. Comments on Working Papers are welcomed, and may be sent to els.contact@oecd.org.

This series is designed to make available to a wider readership selected labour market, social policy and migration studies prepared for use within the OECD. Authorship is usually collective, but principal writers are named. The papers are generally available only in their original language – English or French – with a summary in the other.

This document and any map included herein are without prejudice to the status of or sovereignty over any territory, to the delimitation of international frontiers and boundaries and to the name of any territory, city or area.

© OECD 2016

You can copy, download or print OECD content for your own use, and you can include excerpts from OECD publications, databases and multimedia products in your own documents, presentations, blogs, websites and teaching materials, provided that suitable acknowledgment of OECD as source and copyright owner is given. All requests for commercial use and translation rights should be submitted to rights@oecd.org.

**Abstract**

In tandem with the diffusion of computer technologies, labour markets across the OECD have undergone rapid structural transformation. In this paper, we examine i) the impact of technological change on labour market outcomes since the computer revolution of the 1980s, and ii) recent developments in digital technology – including *machine learning* and robotics – and their potential impacts on the future of work. While it is evident that the composition of the workforce has shifted dramatically over recent decades, in part as a result of technological change, the impacts of digitalisation on the future of jobs are far from certain. On the one hand, accumulating anecdotal evidence shows that the potential scope of automation has expanded beyond routine work, making technological change potentially increasingly labour-saving: according to recent estimates 47 percent of US jobs are susceptible to automation over the forthcoming decades. On the other hand, there is evidence suggesting that digital technologies have not created many new jobs to replace old ones: an upper bound estimate is that around 0.5 percent of the US workforce is employed in digital industries that emerged throughout the 2000s. Nevertheless, at first approximation, there is no evidence to suggest that the computer revolution so far has reduced overall demand for jobs as technologically stagnant sectors of the economy – including health care, government and personal services – continue to create vast employment opportunities. Looking forward, however, we argue that as the potential scope of automation is expanding, many sectors that have been technologically stagnant in the past are likely to become technologically progressive in the future. While we should expect a future surge in productivity as a result, the question of whether gains from increases in productivity will be widely shared depends on policy responses.

**Résumé**

Parallèlement à la diffusion des technologies numériques, les marchés du travail dans la zone OCDE ont subi une rapide transformation structurelle. Dans cet article, nous allons examiner i) l'impact des changements technologiques sur la performance du marché du travail depuis la révolution informatique des années 1980 et ii) les développements récents en matière de technologie numérique, y compris de l'apprentissage machine [*machine learning*] et de la robotique, ainsi que leurs impacts potentiels sur l'avenir du travail. Bien qu'il soit évident que la composition de la main-d'œuvre a radicalement changé au cours des dernières décennies, en partie en raison de l'évolution technologique, les impacts de la numérisation sur l'avenir des emplois sont loin d'être certains. D'une part, il semblerait que la portée potentielle de l'automatisation s'est développée au-delà du travail de routine, rendant les changements technologiques potentiellement de plus en plus générateurs d'économies de main-d'œuvre : au cours des prochaines décennies, selon des estimations récentes, 47 % des emplois américains pourront être automatisés. D'autre part, il existe des preuves suggérant que les technologies numériques n'ont pas créé beaucoup de nouveaux emplois pour remplacer les anciens et une estimation de la limite supérieure montre que la main-d'œuvre des États-Unis n’est utilisée qu’à hauteur de 0,5 % dans les industries numériques qui ont émergé au cours des années 2000. Néanmoins, à ce jour, sur la base d’une première estimation, il n'y a aucune preuve que la révolution informatique ait réduit la demande globale pour les emplois dans les secteurs de l´économie qui sont technologiquement en stagnation, y compris dans les soins de santé, l’administration et les services aux personnes, qui continuent à engager du personnel et à créer de larges possibilités d'emploi. À l'avenir, cependant, nous estimons que la portée potentielle de l'automatisation est en pleine expansion, de nombreux secteurs qui ont été technologiquement stagnants par le passé sont susceptibles de progresser technologiquement à l'avenir. Par conséquent, nous devons nous attendre à une future hausse de la productivité. En revanche, la question de savoir si les gains provenant des augmentations de productivité seront amplement partagés dépend des réponses politiques.

## TABLE OF CONTENTS

Abstract ... 3
Résumé ... 3
Introduction ... 6
An Overview of Labour Market Trends ... 10
The Skill Premium: Skill-biased Technological Change ... 10
Job Polarisation: Routine-Biased Technological Change ... 12
The Labour Share of Income: Capital-Biased Technological Change ... 14
Creative Destruction in Labour Markets ... 15
Deindustrialisation: The Rise of the Service Economy ... 15
The Changing Composition of the Workforce ... 16
Technology or Globalisation? ... 17
Premature Deindustrialisation ... 18
Job Destruction: The Expanding Scope of Automation ... 20
Job Creation: New Tasks, Occupations, and Industries ... 23
Skill Requirements in the Digital Economy ... 28
Challenges for Policy ... 31
Inequality, Skill Shortages, and Social Mobility ... 31
Institutions and Technology Adoption: Cross-Country Differences ... 34
Labour Market Policies for Inclusive Growth ... 35
Human Capital and Regional Development ... 37
Conclusions ... 43
References ... 44

### Tables

Table 1 Most and least likely jobs to be computerised ... 22
Table 2. Examples of new tasks ... 24
Table 3. Examples of new and emerging occupations ... 25

### Figures

Figure 1. Increasing returns to education in the United States ... 10
Figure 2. Returns to skill in selected OECD countries ... 12
Figure 3. Labour market polarisation in selected OECD countries, 1993-2010 ... 13
Figure 4. The declining labour share of income in selected OECD countries, 1980-2010 ... 14
Figure 5. The changing structure of employment in the OECD, 1980-2007 ... 16
Figure 6. Premature deindustrialisation ... 19
Figure 7. Employment in ICT sector and sub-sectors OECD, 2013 ... 26
Figure 8. Contribution of ICT sector to employment growth in the OECD ... 26
Figure 9. Employment changes in selected OECD countries, 1990-2010 ... 28

Figure 10. Technological progress is changing workplaces in the OECD ..... 29
Figure 11. Computerisation will mainly affect low-skill and low-income workers ..... 32
Figure 12. Differences in digital skills by level of parental education ..... 33
Figure 13. EPL and technology adoption in selected OECD countries, 2013..... 35
Figure 14. Regional inequalities have increased since the 1980s..... 38
Figure 15. The Computer Revolution and the reversal in new job creation ..... 39
Figure 16. New industry creation and skills ..... 39
Figure 17. Cities at risk..... 41

## Introduction

Technological breakthroughs of the twentieth century—including electrification, the invention of the automobile and the semiconductor—created rapid growth and vast employment opportunities in entirely new occupations and industries. Whether the digital revolution will be able to repeat these achievements is now subject of intense debate. Gordon (2012), in particular, provides a gloomy account of growth in the twenty-first century, arguing that the digital revolution has been less transformative than previous technological revolutions, contributing only to a short-lived revival of productivity growth. Meanwhile, anecdotal evidence is accumulating suggesting that the pace of technological change is accelerating, with pervasive effects on labour markets. Brynjolfsson and McAfee (2014), for example, have persuasively argued that the digital revolution constitutes a "Second Machine Age", where technological innovations promises to radically increase productivity in a wide range of industries, but that new technologies are also having adverse effects on particularly low- and middle-skilled workers. In their view, stagnant median wages and the falling labour share of income can be explained by rapid capital for labour substitution, induced by cheaper and better digital technologies.

An empirical puzzle is therefore that productivity growth recently has faltered. Regardless of whether new technologies are complementing the skills of workers or substituting for them, a surge in productivity should follow. While various explanations for this productivity puzzle have been proposed, there is little consensus in the literature. According to Gordon (2012), sluggish productivity growth is the result of less rapid technological progress, implying that the anecdotal evidence exaggerate the employment effects of digital technology. Brynjolfsson and McAfee (2014), on the other hand, suggest that the productivity statistics inadequately capture the rise of the sharing economy and the plethora of cheap or free digital services such as Google, Skype, and Wikipedia.[1] A third explanation has been put forward by Summers (2015), arguing that the productivity statistics fail to adequately capture quality improvements: even though health care is more expensive today than in the 1980s, most people would prefer today's health care at current prices, implying that there has been deflation in the health care sector rather than inflation as the price indexes used would suggest. To be sure, this explanation requires unmeasured quality to have increased, but that is indeed likely to be the case, given that the health care share of GDP has increased and advanced economies have experienced a transition from manufacturing to services. Finally, compositional factors may play a role if there has been a rising polarisation in productivity across companies: according to a recent OECD study, productivity growth in the 2000s only slowed for laggard firms, contributing a growing productivity gap between leading companies and laggards (Andrews et al., 2015).[2] Moreover, an increased variance in the distribution of profits across firms is particularly evident in sectors that invest heavily in ICT (Brynjolfsson et al., 2009; Bartelsman et al., 2010).

Meanwhile, there are reasons to believe that most productivity gains associated with the digital revolution lie ahead: according to estimates by Frey and Osborne (2013), nearly half of jobs in the United States are susceptible to automation over the forthcoming decades. Indeed, many of the technological developments highlighted by Frey and Osborne (2013), such as autonomous vehicles, are yet to find widespread use. Similarly, while cashiers can be displaced by existing self-service technology, there are still more than 3 million cashiers in employment in the United States. In other

1. Similarly, Brynjolfsson & Hitt (2000) argue that a central impact of ICT is that it enables firms to reorganise business processes and work practices, which means that standard growth accounting estimates tend to underestimate the productivity contributions of ICT (also see Corrado & Hulten, 2010).

2. Barth et al. (2014) and Bloom et al. (2015) similarly show that nearly the rise in the dispersion of wages in the United States since the 1970s is accounted for by an increased dispersion of wages across firms.

words, the present speaks to past historical episodes suggesting that new technologies are not necessarily associated with immediate productivity improvements: the period of electrification, for example, was characterised by an initial slowdown in productivity as the workplace was reorganised around the electrical motor (David, 1990; Syverson, 2013).[3] More recently, it has been shown that the firm-level productivity gains from computer adoption are substantially larger over a longer time horizon as it similarly requires complementary organisational changes (Brynjolfsson and Hitt, 2003), and that productivity follows investment in digital technologies with lags of between five and 15 years (Basu and Fernald, 2007). Yet, while such evidence is suggestive of future productivity gains, the existence of implementation lags cannot square the recent disemployment of low- and middle skilled workers with sluggish productivity growth.

Explanations for disemployment among certain skill groups further vary from pointing towards either technology or globalisation as the culprit, or a combination of the two.[4] Although there is an emerging consensus that technology is having pervasive impacts on labour markets, whether future technological developments are likely to simply shift the occupational structure with no net negative effect on overall employment, as has been the case historically, or whether the digital revolution will reduce the demand for jobs, is another contested question. For example, nearly half of the respondents to a recent Pew Research survey, among 1,900 economists and technology experts, believe that technology will create fewer jobs than it destroys over the next decade (Smith and Anderson, 2014). Yet, while some pundits have proclaimed the "end of work" (Rifkin, 1995; Ford, 2009), others are more sceptical, pointing to the *Polanyi paradox* –"we know more than we can tell" – reflecting that we sometimes only tacitly know how to perform certain tasks.[5] Rooted in Polanyi's observation, Autor (2015) thus answers the pertinent question "why are there still so many jobs?" by arguing that a wide range of work is still difficult to automate since it involves tasks that require intuition or human judgment. Similarly, Frey and Osborne (2013) show that jobs requiring creativity and complex social interactions are at low risk of automation also in the future. While this implies that "end of work" scenarios are overblown, we cannot exclude the possibility that technology over time may reduce the demand for workers, especially for certain skill groups (Sachs and Lawrence, 2012).

Against this background, this paper provides a systematic review of the literature examining the impact of digitalisation on OECD labour markets, seeking to shed some light on the above described debates. Examining the impact of computer technologies on labour markets across the OECD, we

3. Reaching even further back in history, Crafts (2004) examines the contribution of the steam engine to British economic growth during the Industrial Revolution, showing that its contribution was miniscule prior to 1830, some 60 years after the invention of the Watt steam engine. Instead, the peak economic impact of the steam engine appeared almost a century after its invention, as advances in high-pressure technology in allowed the technology's full potential to be realised. Interestingly, comparing the economy-wide impact of steam with the contribution of ICT today, Crafts (2004) concludes that the impact of steam was modest in comparison.

4. A recent study by Autor et al. (2013) suggests that local labour markets exposed to import competition has experienced net reductions in net employment, while places that are relatively susceptible to automation have witnessed job polarisation, but no net reduction in employment. At the same time, however, evidence is accumulating suggesting that technology is increasingly affecting also labour markets in emerging economies, including China, India, and Brazil, where the manufacturing share of employment has already peaked well below the levels experienced by advanced economies in their early stages of industrial development. Rodrik (2015), in particular, has forcefully argued that such "premature deindustrialisation" is the result of a combination of technology and globalisation, leading some countries to import deindustrialisation as developments in robotics and additive manufacturing allows companies to move production to automated factories close to domestic markets.

5. See Polanyi (1966).

show that recent technological change has been skill-, routine-, and capital-biased, contributing to significant shifts in income shares between workers at different levels of the skill distribution, as well as between labour and owners of capital. In particular, we show that over the course of the twentieth century, technological change has favoured relatively skilled workers: a trend that has accelerated since the 1980s, as reflected in the increasing returns to skill across OECD countries (OECD 2013a). Nevertheless, the skill-biased technological change (SBTC) model cannot account for two empirical puzzles that are prevalent in nearly all OECD labour markets: non-monotonic shifts in employment and wages along the skill distribution. Building on intuitions from computer and organisational sciences about the type of tasks computers can perform, a growing literature shows that routine-biased technological change (RBTC) —stemming from computers substituting for workers performing routine activities— can account for recent job polarisation (Autor et al., 2003). Consistent with the RBTC hypothesis, recent decades have seen the demise of the jobs of bookkeepers, paralegals, and secretaries as tax preparation, word processing, and spreadsheet software diffused in the workplace. As routine jobs have disappeared, labour markets throughout the OECD economies have experienced a "hollowing out" with significant expansions of employment at both ends of the skill spectrum (Goos et al., 2007; 2009; 2014). Importantly, a large body of work documents that these shifts are directly accounted for by the spread of computer technology (Autor and Dorn, 2013; Michaels et al., 2014; Graetz and Michaels, 2015), downplaying alternative explanations emphasizing the role of offshoring, low-skill immigration, trade, or a secular decline in manufacturing employment.

Third, we document a trend towards capital-biased technological change (CBTC). A growing literature show that the labour share of income has seen a global decline over recent decades: 42 out of 57 countries examined by Karabarbounis and Neiman (2014) experienced a fall in their labour share of income, and the median OECD country has seen a decrease in the labour share of about 5 percentage points since the early 1990s (OECD, 2012). Despite employment growth at the bottom end of the skill distribution the wage share of the least educated have also declined (OECD, 2012), with the gains concentrated to the top income earners (Alvaredo et al., 2013). Examining alternative explanations for the decreasing share of income that accrue to workers, such as the demise of collective bargaining and trade competition, we conclude that the main explanatory factor is that firms have been induced to substitute capital for labour, driven by a trillionfold decline in the price of computing (Nordhaus 2007).

Having established these features of recent technological change, we proceed to examining its impacts on the composition of the workforce, discussing implications for the future of jobs and productivity. In particular, we document that technological change has been a key driver behind the rapid deindustrialisation taking place across OECD economies. We suggest that this trend is likely to continue over the forthcoming decades, as technological change is seemingly becoming less job creating and more labour saving. Recent work by Frey and Osborne (2013), for example, suggests that the potential scope of automation is rapidly expanding, potentially constituting a watershed for labour markets. Applying their methodology, several studies have shown that a substantial share of jobs across the OECD economies are now automatable, as a result of recent advances in Mobile Robotics and Machine Learning technology, including autonomous vehicles, data mining, machine vision, computational statistics and other sub-fields of Artificial Intelligence. Jobs at high risk of automation are typically found at the lower end of the skill spectrum, in sectors such as administration, office work, production, sales, services, and transportation, suggesting that the adverse impacts of technology is shifting from middle-skill to low-skill workers.

Meanwhile, rates of new job creation have slowed down significantly since the computer revolution of the 1980s: although estimates suggest that ICT investments have a positive contribution to productivity growth, the direct impacts on job creation of such investments have so far been

disappointing.[6] During the 1980s, some 8.2 percent of US workers shifted into jobs that appeared for the first time during that decade, while by the end of the 1990s that share had almost halved to 4.4 percent (Lin, 2011). Furthermore, technology seems to have generated even fewer jobs in the twenty-first century. Estimates by Berger and Frey (2016a) show that the emergence of new technology-related industries throughout the 2000s —including online auctions, video and audio streaming, and web design— has had negligible effects on aggregate employment patterns, employing less than 0.5 percent of the US workforce. Job opportunities in these industries are further largely confined to highly skilled workers with STEM degrees, which explain why they pay more than twice the U.S, median wage. More generally, the ICT sector is only absorbing a small share of workers: while some 14.4 million OECD workers were employed in the ICT sector and sub-sectors, they constitute less than 3 percent of total employment.

Instead, most job growth in advanced economies has recently come from either technology-using (e.g., professional services) or technologically stagnant sectors (e.g., health care, government, and personal services). Between 1990 and 2008, technologically progressive sectors of the US economy, accounting for more than 34 million jobs in 1990, grew by a negligible 0.6 million jobs, while technologically stagnant sectors, experiencing slow productivity growth accounted for 98 percent of total job creation (Spence and Hlatshwayo, 2012). Similarly, since the Great Recession, OECD countries have seen most of the job creation in services, with simultaneous employment growth in high-skill professional services and low-skill service jobs in food and accommodation (OECD 2015b). A shift in job creation towards such personal services, in turn, has implications for productivity: because low-skill service sectors often are technologically stagnant, overall productivity growth may slow down as a result (Baumol, 1967). Furthermore, as economic growth and job creation is increasingly taking place in different sectors of the economy, income is becoming more unevenly distributed.[7]

More speculatively, we argue that the expanding scope of automation has the potential of making many of the sectors that have been technologically stagnant in the past — including health care, education, food and accommodation— technologically progressive in the future. Importantly, while digital technologies may have created few jobs directly, they have already had a substantial impact on skill requirements across existing occupations and industries. For example, some 42 percent of OECD workers are employed in firms that have introduced new technologies that have already changed work routines or skill requirements in the past three years (OECD, 2013a). Furthermore, out of more than 900 occupations reviewed, only two do not use any type of digital technology. In particular, there is evidence to suggest that as digital technologies have diffused across a wider range of occupations and industries, the demand for workers with analytical, interactive, and problem-solving skills has surged (Autor et al., 2003; Berger and Frey, 2016b). In tandem with technologically

6. Standard growth accounting exercises suggest that ICT contributed some 0.6 and 1.0 percentage points to EU and US labour productivity growth between 1995-2005 (O'Mahony and Timmer, 2009), though recent evidence from the US suggest that such productivity gains mainly accrue to ICT-producing, rather than ICT-using, industries (Acemoglu et al., 2014).

7. The indirect contribution of new technology jobs is however still significant as they create additional demand for local services. For example, Moretti (2010) has estimated that one additional job in the tradable high-technology sector generates about 4.9 new jobs locally in the non-tradable sector, as skilled workers with higher incomes create additional demand for local services. Similarly, across European regions, estimates suggest that local high-tech job multiplier is around five (Goos et al., 2015). Thus, while technology does perhaps not create as many jobs directly as in the past, its indirect impact on service employment is substantial. Nevertheless, because new technology jobs overwhelming cluster in highly skilled cities, low skilled workers will inevitably have to follow, making economic activity increasingly geographically concentrated.

stagnant sectors becoming more prone to technological change, the demand for technical skills is likely to increase. We conclude by discussing policy challenges associated with these trends, outlining a range of responses aimed at raising productivity, while mitigating unwanted increases in inequality and expanding economic opportunity.

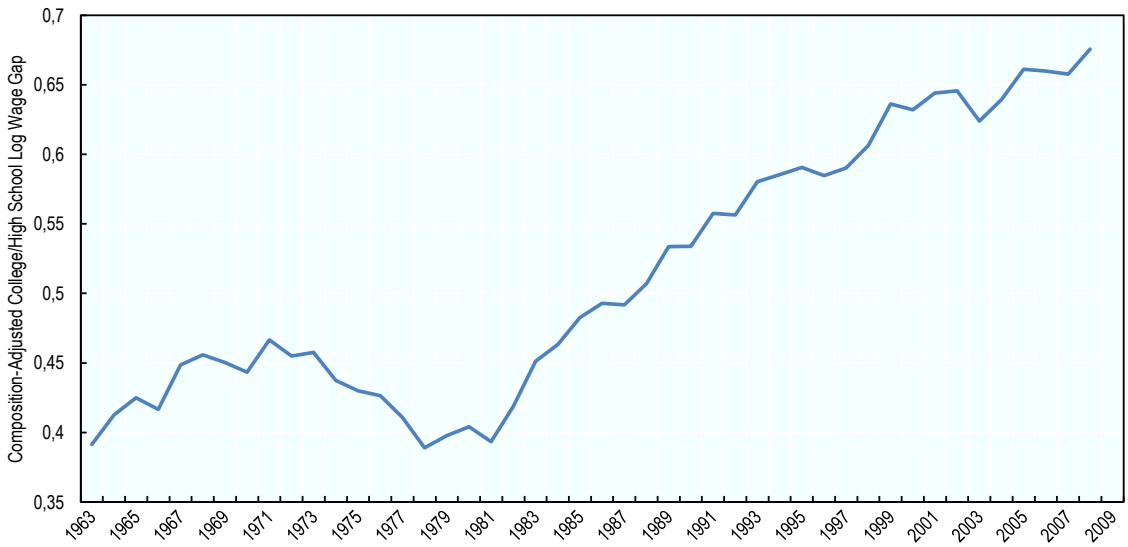
## An Overview of Labour Market Trends

### *The Skill Premium: Skill-biased Technological Change*

A large body of work has documented an increase in wage inequality across advanced countries commencing in the 1980s, pointing at SBTC as its primary cause. The intellectual foundation underpinning most such analysis goes back to Jan Tinbergen (1974; 1975), arguing that shifts in the return to skill result from a "race between education and technology", thus reflecting supply and demand factors. Similarly, in the canonical model outlined by Acemoglu and Autor (2011), technology is assumed to take a factor-augmenting form, complementing either high- or low-skill workers, causing monotone increases or decreases in relative wages between skill groups. Thus, in this framework, increasing returns to skill imply that the supply of skills is not keeping pace with the demand created by technological change.

Over the past century, the canonical model has provided a useful framework for analyzing trends in the labour market, as technological advances have benefited relatively more skilled workers (Berman et al., 1994; Acemoglu, 1998; Goldin and Katz, 2008). Following the switch to electricity in the early twentieth century, technology-skill complementarities emerged in manufacturing as electric motors and new production methods were adopted (Goldin and Katz, 1998). More recently, empirical evidence similarly suggests that the arrival of new computer technologies overwhelmingly has favored relatively skilled workers: as shown in Figure 1, after faltering in the 1970s, the wage gap between college and high-school graduates in the United States widened considerably from the early 1980s onwards, as computers diffused across the workplace at the same time as the relative supply of college-educated workers stagnated (Autor, 2014).

Figure 1. **Increasing returns to education in the United States**




*Notes*: This figure shows the college/high school (log) wage gap in the United States based on the weighted average of predicted earnings for full-time, full-year workers adjusted for differences in education, experience, and race based on CPS data.

*Source*: Acemoglu and Autor (2011).

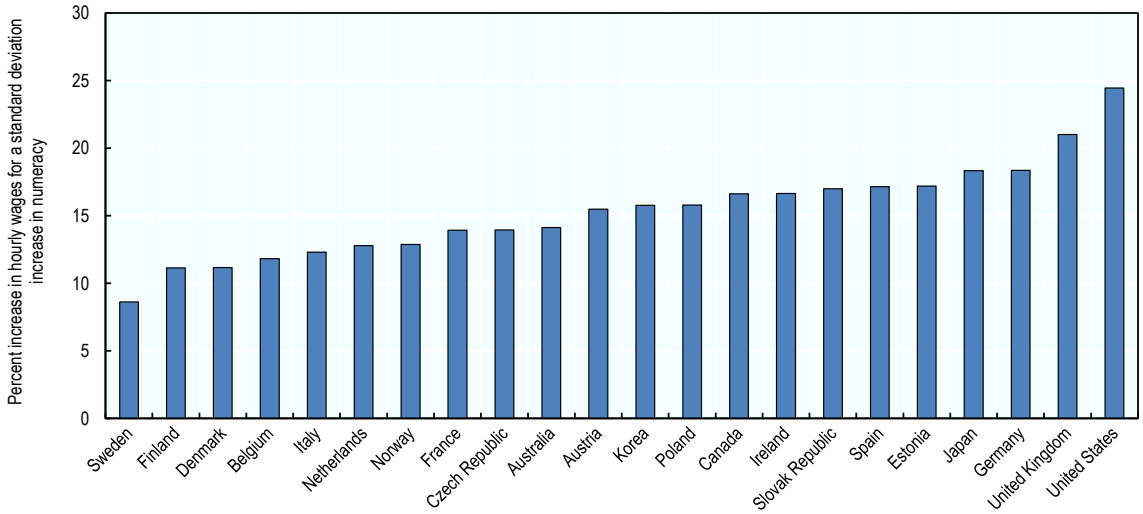
The prevalence of computer-skill complementarities has been well documented.[8] Cross-country studies show that computers are more extensively adopted in countries with an abundance of skilled workers (Caselli and Coleman, 2001). Similarly, within countries, metropolitan areas with a larger relative supply of college-educated workers have adopted computers faster, and returns to skill surged as computer adoption accelerated (Beaudry et al., 2010). A number of studies have also tried to estimate the returns to using a computer on-the-job, finding that computer use is associated with an increase in wages by some 8-15 percent (Krueger, 1993; Spitz-Oener, 2008), although some studies have challenged whether these effects are truly causal. DiNardo and Pischke (1997), for example, document equally large wage gains accruing from on-the-job use of telephones and pencils, which would suggest that the wage premium associated with computer use partly reflects omitted factors. Similarly, while evidence from Germany, Ireland, and Italy finds no significant effects on firm productivity due to increased access to broadband infrastructure (Colombo et al., 2013; Bertschek et al., 2013; Haller and Lyons, 2015), the available evidence on balance suggests that broadband access and computer use has a positive causal impact on the wages of skilled workers (Spitz-Oener, 2008; Grimes et al., 2012; Akerman et al., 2015).[9]

Although most OECD countries have experienced similar technological developments over past decades, there is substantial variation in the skill premium across countries and regions (see Figure 2). In Europe, greater increases in the supply of educated workers has moderated increases in the returns to skill: between 1990 and 2005, the enrollment of undergraduates increased by more than 30 percent in Italy, Ireland, and Spain, while it increased by nearly 50 percent in the Scandinavian countries (Crivellaro, 2014). As a result, the Scandinavian countries exhibit the lowest returns to skill among OECD member countries: evidence from the PIAAC survey suggest that returns vary between 12 percent in Sweden to 28 percent in the United States (Hanushek et al., 2015). Furthermore, a considerable body of work argues that the stricter labour market institutions in Europe have moderated increases in the returns to skill. Evidence from the United Kingdom, for example, suggest that both a higher union density and minimum wage laws served to reduce wage inequalities (Machin, 1997; Dickens et al., 1999) and panel data evidence from the OECD similarly suggest that stricter employment protection, more generous unemployment benefits, and minimum wages are associated with lower levels of wage inequality (Koeniger et al., 2007). To be sure, institutional factors – such as the enactment of minimum wages and de-unionisation – have had independent effects on the wage distribution. Yet, as argued more than two decades ago by Katz and Murphy (1992), the SBTC framework remains "a key component of any consistent explanation for rising inequality and changes in the wage structure".

8. Machin and Van Reenen (1998) document a link between skill upgrading and R&D intensity in seven OECD countries, which is supportive of skill-biased technological change and Autor et al. (1998) show that skill upgrading was more rapid in industries that intensively used computer technology.

9. Ingram & Neumann (2006) show that once other measures of skill (for which educational attainment is a proxy) are accounted for, returns to education has remained constant since the 1970s. In particular, the rising returns to education reflect an increase in the returns to cognitive skills, such as mathematical ability. Interestingly, such "abstract" skills are typically a complement to computer technology (Autor et al., 2003).

Figure 2. **Returns to skill in selected OECD countries**




*Notes*: This table reports the coefficients on numeracy scores from country-specific regressions of log hourly wages (including bonuses) of wage and salary earners (in PPP corrected USD) on proficiency scores standardised at the country level. Note that data for BEL and GBR only cover Flanders (BEL) and England/Northern Ireland (GBR) respectively.

*Source:* OECD (2015a).

### *Job Polarisation: Routine-Biased Technological Change*

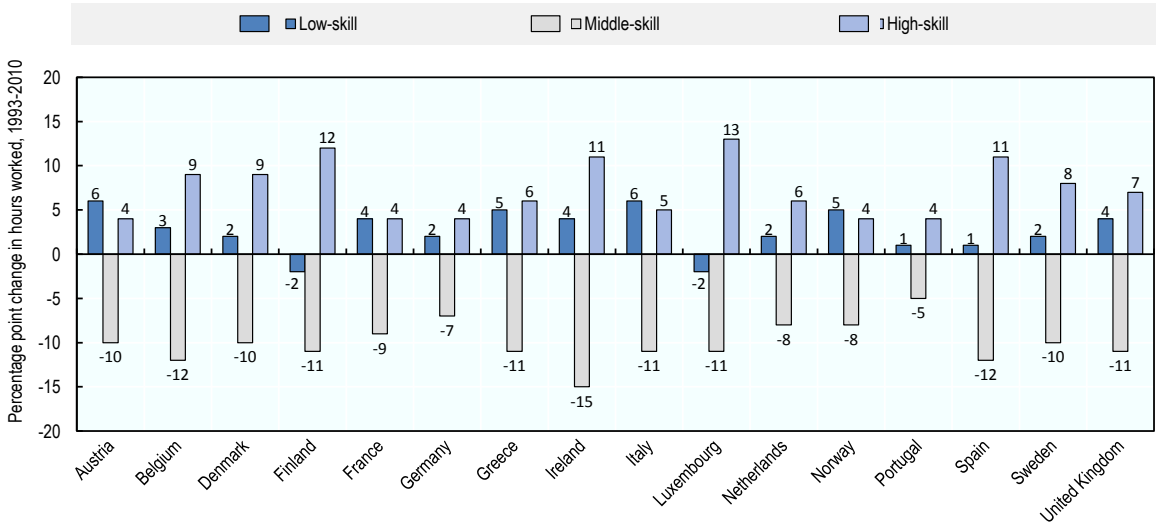
While the canonical model has provided a useful framework for understanding changes in the returns to skill, it cannot explain the recent non-monotonic employment growth by skill level experienced by most OECD economies. In particular, although high-skilled jobs have exhibited rapid employment growth, employment in low-skilled jobs has similarly surged, at the expense of employment in middle-skill occupations. The canonical model is equally silent on non-monotonic changes in the wage distribution, which largely mirrors the polarisation of employment across skill levels.

Alternative models seeking to understand these shifts have provided a task-based approach, suggesting that new technologies do not unambiguously favour more skilled workers, but tend to complement workers in certain job tasks, while substituting for them in others (Acemoglu and Autor, 2011). In particular, the task model introduced by Autor et al. (2003), suggests that computers tend to substitute for workers in routine tasks that follow well-defined rule-based procedures, while they complement workers performing more complex abstract tasks, such as problem-solving and complex communication activities. Because of the complementarity between computers and abstract tasks in production, and the complementarity between goods and services in consumption, computerisation can also explain the recent surge in low-skill service jobs, as higher incomes increase the demand for such services, and the manual non-routine tasks that are prevalent in service occupations are not substitutable by computers (Autor and Dorn, 2013).[10] In other words, the task model can account for non-monotonic employment changes in the skill distribution, with simultaneous growth in the bottom and top of the distribution accompanied by a substantial contraction of middle-skill jobs, which are commonly intensive in routine tasks.

10. An alternative explanation for the growth of low-skill jobs instead emphasises the shift of home production to market services as women increasingly entered the labor force (Mazzolari and Ragusa, 2012).

These predictions have not only proved to be theoretically intuitive, but also empirically accurate, and seemingly hold across industries as well as geographies. Industries investing more in computer capital have experienced subsequently greater reductions in workers performing routine tasks, while the share of workers performing non-routine cognitive tasks expanded in tandem—importantly these shifts are shown to be pervasive within gender, education, and occupation groups (Autor et al., 2003). Similarly, studies of local labour markets across the United States show that places with an initially higher share of routine jobs experienced greater investments in computers, leading to a pronounced polarisation of these labour markets as workers shifted into low-skill service jobs (Autor and Dorn, 2013). Importantly, the explanatory power of RBTC holds also when pitted against alternative determinants such as the demise of manufacturing, offshoring, and immigration.

Figure 3. **Labour market polarisation in selected OECD countries, 1993-2010**




*Notes*: This figure shows percentage point changes in hours worked in low-, mid- and high-skill occupations in 16 OECD countries between 1993 and 2010.

*Source*: Goos et al. (2014).

The RBTC hypothesis also seemingly holds across most of the OECD. A number of recent studies document job polarisation in most European countries (Goos et al., 2007; 2009; 2014), including Germany, France, Sweden, and the United Kingdom, but also in countries like Portugal and Greece (see Figure 3).[11] These findings are further consistent with recent firm-level evidence: exploiting the staggered rollout of high-speed broadband services in Norway as a natural experiment, Akerman et al. (2015) document a causal impact of ICT investment on workers performing different tasks. Consistent with the RBTC hypothesis, access to high-speed broadband improved the wages and labour market outcomes of workers performing non-routine abstract tasks, whereas it substituted for workers performing routine tasks. Taken together, the available evidence thus suggests that computer capital substituting for workers in routine jobs is a key factor in understanding why OECD labour markets have polarised over past decades.

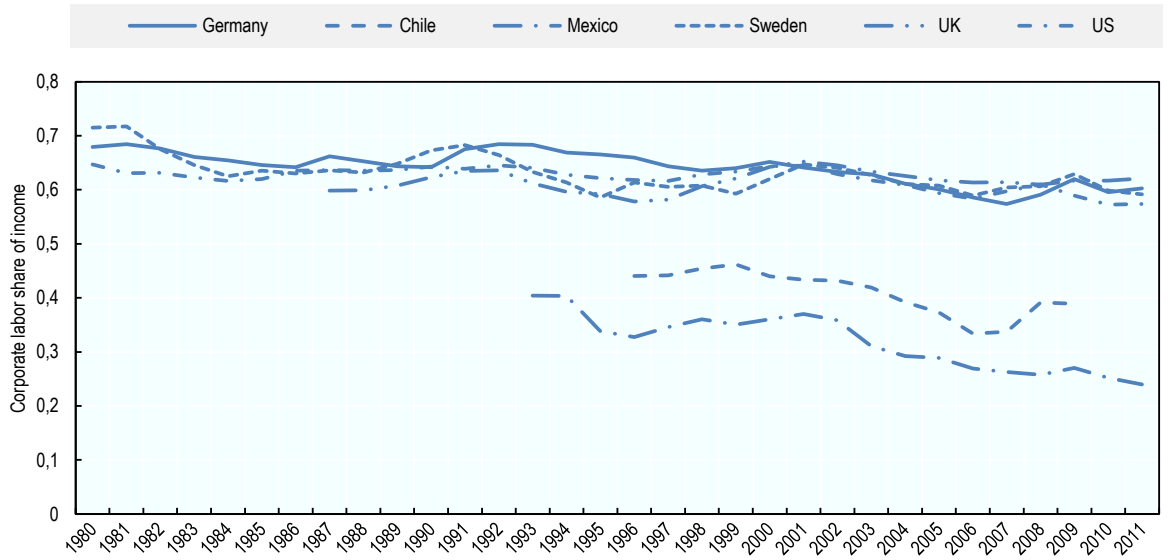
11. In a similar way, the World Bank (2016) provides evidence that labour market polarisation has been evident in most developing countries over the past decades.

**The Labour Share of Income: Capital-Biased Technological Change**

In 1957, Nicholas Kaldor famously published six stylised facts about economic growth.[12] Based on the remarkable historical consistency in the labour share of income – including wages, salaries, and benefits – he concluded that the share of income accruing to capital and labour are roughly constant over longer periods of time; an assumption that is still present in many contemporary growth models. Yet, following a secular decline in the labour share of income across countries in recent decades, this assumption no longer seems to hold.

In the median OECD country, the labour share dropped from 66.1 percent in the early 1990s to 61.7 percent in the late 2000s (OECD, 2012). When the incomes of the top - 1 percent earners are excluded the labour share decline is even more pronounced: on average, labour's share of income for the other 99 percent of earners fell by an additional 0.9 percentage points relative to the unadjusted labour share (OECD, 2012). Similarly, examining 59 countries, for which data is available for at least 15 years, Karabarbounis and Neiman (2014) show that the labour share of income declined by more than 5 percentage points globally over the investigated period: a trend that they found to be prevalent across countries with different institutions, labour market conditions, levels of human capital, and access to natural resources. Between 1975 and 2012, more than 70 percent of the countries examined experienced reductions in the share of income accruing to labour, including most OECD countries ranging from Sweden to emerging economies such as Chile and Mexico (see Figure 4).

Figure 4**. The declining labour share of income in selected OECD countries, 1980-2010**




*Notes*: This figure reports the corporate labour share (compensation of employees in the corporate sector divided by corporate gross value added) in five OECD countries.

*Source:* Karabarbounis and Neiman (2014).

One prominent strand of explanations for this phenomenon emphasises the role of labour and product market deregulation in accounting for the simultaneous decline in the labour share of income and increase in unemployment (Blanchard, 1997; Blanchard and Giavazzi, 2003; Azmat et al., 2012). For example, over past decades, most OECD countries have seen a decline in collective bargaining

12. Kaldor (1957).

and union coverage, which may partly explain the lower compensation that accrues to labour. In contrast, other studies have pointed towards shifts in the capital-output ratio, driven by factors like the price of imported goods or CBTC (Bentolila and Saint-Paul, 2003). Nevertheless, while deregulation and privatisation can account for a substantial share of the decline in the labour share within individual industries, it seems to have had a limited effect on aggregate changes in the labour share: across countries there is no clear relationship between changes in collective bargaining coverage and changes in the labour share since the early 1990s.[13] Furthermore, some of the largest declines have been observed in countries such as Finland and Sweden, where bargaining coverage increased over the investigated period (OECD, 2012). Similarly, while it is plausible that the declining labour share is a result of considerable shifts in the global labour supply, following the integration of China and India into the global economy, available estimates suggest that a meagre 10 percent of the decline of the labour share in OECD countries between 1990 and 2007 can be accounted for by import competition from low-wage countries (OECD, 2012), and the fact that the labour share has also declined in these countries speaks against a factor-based explanation. In a similar way, although structural change may have induced a declining labour share if countries increasingly specialise in more capital-intensive sectors, this explanation does not seem to hold empirically, since labour shares have declined also within industries.[14]

An emerging consensus is thus forming around the conclusion that technology is the main cause of the declining labour share, as precipitous price declines in capital-producing sectors have induced firms to shift from labour to capital (Karabarbounis and Neiman 2014). In particular, the price of computer equipment has fallen sharply over past decades: between 1945 and 1980, the cost of computations declined by 37 percent per annum; after 1980, annual price declines accelerated to 64 percent, with simultaneous expansion in the capabilities of computers (Nordhaus, 2007). More broadly, the relative price of investment goods has declined by some 25 percent globally since 1975 (Karabarbounis and Neiman, 2014). Consistent with the argument that ICT has raised productivity by creating new capital goods and business processes, while substituting for workers in routine jobs, capital deepening and total factor productivity growth are estimated to account for 80 percent of the within-industry decline in the labour share of OECD countries between 1990 and 2007 (OECD, 2012). Thus, although more research is needed to better disentangle the potential causes behind the declining labour share of national income, the available evidence to date points towards a technology-based explanation.

## Creative Destruction in Labour Markets

### *Deindustrialisation: The Rise of the Service Economy*

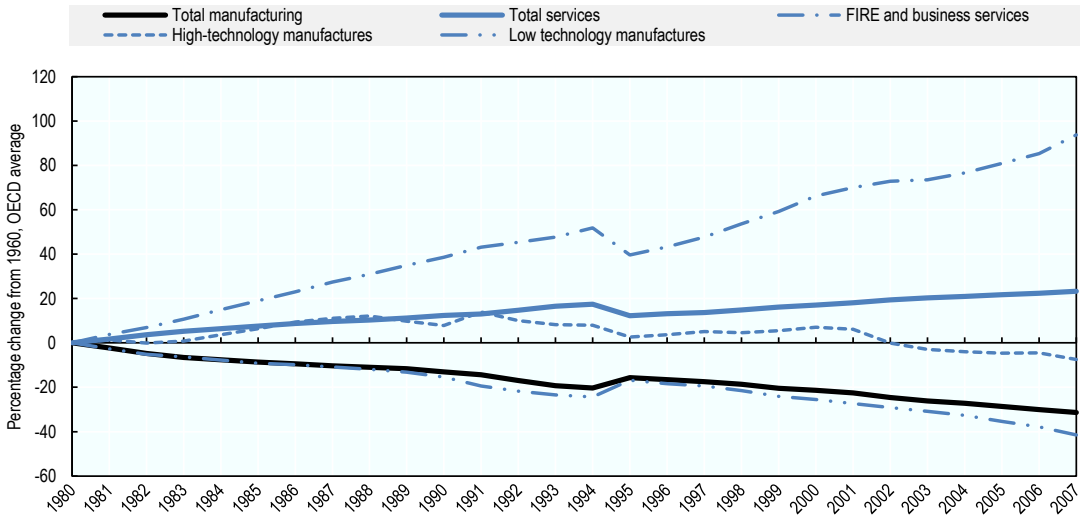
Over recent decades, most advanced economies have witnessed a secular decline in their share of workers employed in manufacturing – a phenomenon often referred to as deindustrialisation. Across the OECD, manufacturing employment has declined by some 30 percent since 1980, particularly in

13. Estimates provided in OECD (2012), for example, suggest that while privatisation of network industries (e.g., communications, energy, and transport) can account for about a third of the decline in the labour share within these industries in OECD countries between 1990 and 2007, it had a limited impact on the changes in the aggregate labour share due to the fact that these industries constituted a limited share of the national wage bill (also see Bassanini & Manfredi, 2012).

14. In most OECD countries, within-industry changes in the labour share can fully account for the decline in the aggregate labour share, with the exceptions of Australia, Denmark, and Korea where structural shifts away from labour-intensive sectors contributed to the aggregate decline. Other OECD countries, such as Austria, Belgium, Sweden, and the United States have in contrast experienced growth in industries with high wage shares, thus partly offsetting aggregate decreases in the labour share (OECD, 2012).

low-technology sectors (see Figure 5). Similarly, between the mid-1960s and 1994, for example, the United States experienced a steep decline in manufacturing, from about 28 to 16 percent of its total civilian workforce and the EU-15 followed a similar trajectory as manufacturing employment fell from a high of around 30 percent in 1970, to 20 percent in 1994 (see Rowthorn and Ramaswamy, 1997). In Japan, deindustrialisation commenced somewhat later and progressed relatively slowly: the manufacturing employment share fell by roughly 4 percentage points over the same period. In this section, we explore the driving forces behind the recent deindustrialisation across countries and its implications for the future of work.

Figure 5. **The changing structure of employment in the OECD, 1980-2007**




*Notes*: This figure shows percentage changes between 1980 and 2007 in employment shares of different sectors in the OECD, based on data in OECD (2013a). Only the OECD countries available in the 1980 STAN database are included for the period 1980-90; only the OECD countries available in the 1991 STAN database are included for the period 1991-94; and only the OECD countries available in the 1995 STAN database are included for the period 1995-2007.

*Source:* OECD (2013a).

## The Changing Composition of the Workforce

Since the Industrial Revolution, the arrival of new technologies and changing consumer preferences has significantly shifted the composition of employment. The rise of manufacturing can in part be explained by Engel's law, suggesting that as per capita incomes rise the proportion of income spent on food will decline, leading workers to transition into sectors experiencing relatively high growth rates such as manufacturing and services. In addition, on the supply side, the discovery and implementation of a wide range of agricultural innovations contributed to productivity growth, allowing labour to shift into other sectors of the economy. As a result, the percent of the total civilian employment in agriculture across advanced economies rapidly declined from 20 percent in the early 1960s to just over 10 percent by the mid-1970s (Rowthorn and Ramaswamy, 1997). In contrast, the transition from manufacturing to services has seemingly not been driven by any significant shifts in expenditure between industry and the service sector. Instead, deindustrialisation appears to reflect the impact of differential productivity growth between manufacturing and services. Because productivity growth in manufacturing has been substantially faster due to factory automation and widespread adoption of industrial robots (e.g., Graetz and Michaels, 2015), the service sector has absorbed an ever greater proportion of total employment to keep its output rising in line with that of manufacturing.

A helpful framework for analyzing recent shifts in employment in the context of deindustrialisation has been provided by Baumol et al. (1989). Building on the observation that productivity growth has been persistently faster in some sectors, they differentiate between technologically progressive sectors, experiencing relatively rapid productivity growth, and sectors that are technologically stagnant. In this framework, the technologically progressive characteristic of manufacturing relates to the standardisation of production procedures, allowing computer technology to be extensively applied in tasks following routine rule-based procedures (Autor et al., 2003). Although this equally applies to some impersonal services, including telecommunications and data processing, most personal services, such as education and food and accommodation services, have at least in the past been difficult to standardise, making them technologically stagnant.

An unbalanced application of technology across sectors has implications for growth and standards of living. For example, if the automotive industry is technologically progressive, and health care is technologically stagnant, the average rate of productivity growth will in the long-run be determined by health care, where productivity growth is slow, meaning that the economy as a whole will be asymptotically stagnant. Thus, Krugman (1994) has suggested that in the light of the tendency towards deindustrialisation, productivity growth in manufacturing is becoming less important for overall productivity growth and living standards. A recent study by Spence and Hlatshwayo (2012) supports this view, showing that technologically stagnant non-tradable sectors of the economy can account for as much as 98 percent of total US employment growth between 1990 and 2008. Around 40 percent of this growth, in turn, came from government and health-care services, which are notably not primarily driven by market forces. At the same time, technologically progressive tradable sectors, accounting for more than 34 million jobs in 1990, grew by a negligible 0.6 million jobs. Importantly, nearly all of those jobs emerged in highly skilled tradable sectors, most prominently, finance, computer design and engineering. Most job losses, in contrast, took place in the electronics industry, agriculture, cut-and-sew apparel manufacturing, fabric mill, aerospace, paper, chemicals, and the auto industry. Yet, the tradable sector accounted for most growth in value-added: whereas value added per employee grew by just about 12 percent in the non-tradable sector, it increased by close to 52 percent in the tradable sector. In other words, productivity growth and job creation is taking place in different sectors of the economy, making income more unevenly distributed.

***Technology or Globalisation?***

While technological progress undoubtedly has been a factor underlying the process of rapid deindustrialisation, its driving forces has been subject of intense debate (see Rowthorn and Ramaswamy, 1997). Because deindustrialisation has coincided with a surge in capital flows and trade expansion between advanced and emerging economies, it is often suggested that there is a causal link from globalisation contributing to stagnant real wages and rising earnings inequality across the developed world. However, the early studies of the 1990s, including Lawrence et al. (1993) and Krugman and Lawrence (1994) suggested that stagnant or declining unskilled wages in general, and the growing inequality of earnings between skilled and unskilled workers in particular, had little to do with trends in globalisation as imported goods from the developing world constituted an almost negligible share of GDP. Instead, they argued that these trends were driven by other factors, such as SBTC. In an influential paper, for example, Krueger (1993) found that workers using computers at work earn roughly 10 to 15 percent more, other things being equal. Because more highly educated workers are more likely to use computers at work, and since computer use expanded tremendously in the 1980s, the work of Krueger (1993) suggested that computer use can account for a substantial share of the increase in the rate of return to education, and thus the widening earnings inequality between skilled and unskilled workers.

Other scholars, such has Wood (1995a,b) and Freeman (1995), in contrast, contested that imports from the developing countries has had a more substantial impact on labour markets in advanced economies than the value of the output being imported would suggest, as production in developing countries is highly labour intensive, and the price of labour is low. In other words, global trade could significantly contribute to job losses, especially for unskilled workers in advanced economies, even if the share of imports from developing countries had been low in monetary terms. More recently, however, even the value of imports from developing economies has surged in tandem with the rise of China: between 1991 and 2007, the annual value of US imports from China increased by a staggering 1,156 percent (Autor et al., 2015). In the light of accumulating evidence on the impact of trade on labour markets in advanced economies, Krugman (2008), whose earlier work on globalisation and wages suggested that the impact of trade on US earnings had been negligible, has recently argued that: "It's no longer safe to assert that trade's impact on the income distribution in wealthy countries is fairly minor. There's a good case that it is big, and getting bigger." In particular, work by Autor et al. (2013), examining the impact of Chinese imports on local labour markets in the US, shows that recent import shocks has contributed to reductions in both employment and wage levels, also beyond manufacturing.

Untangling the impacts of technology and trade on earnings and employment is however difficult, not least because rapid technological change associated with the computer revolution and the most recent expansion of international trade are largely contemporary events. Furthermore, technological change has been a key driver of globalisation: innovations, including containerisation and sophisticated ICT, have been fundamental in allowing companies in advanced economies to shift production to locations where labour is relatively cheap. A vast literature has also documented labour market-impacts of offshoring, showing that while routine-intensive production work initially was most susceptible, the scope of offshoring has more recently expanded to include technology-intensive service jobs, which have also left the OECD for low-cost locations (OECD 2013b). Furthermore, while offshoring can account for only a small share of realised job losses, the offshoring potential remains substantial: a widely cited study by Van Welsum and Vickery (2005), for example, has estimated that 20 percent of OECD employment is *potentially* offshorable.[15]

Nevertheless, because local labour markets have specialised in work that is not equally susceptible to imports and computerisation, it is possible to examine how these phenomena have affected labour markets differentially. For example, in a recent study, Autor et al. (2013) show that between 1980 and 2007, labour markets whose initial industry composition exposes them to rising Chinese import competition experienced significant falls in employment, particularly in manufacturing and among non-college workers. By contrast, labour markets susceptible to automation technology due to specialisation in routine work experienced job polarisation, both within and beyond manufacturing, but no net employment decline. In other words, while globalisation can account for some of the rise in unemployment, computerisation has been the key driver behind recent job polarisation and widening earnings disparities.

***Premature Deindustrialisation***

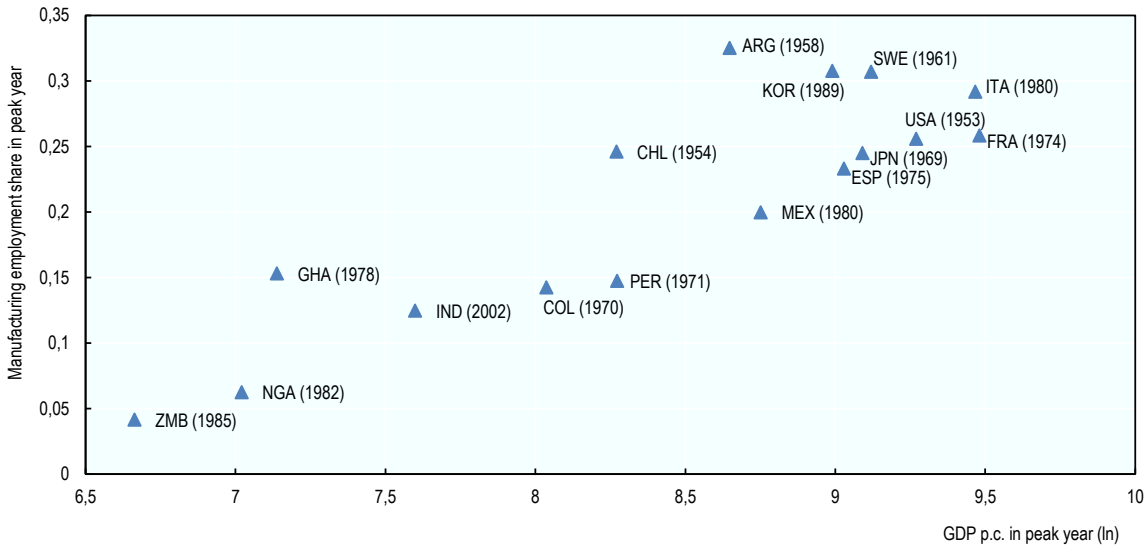
In tandem with advanced economies experiencing rapid deindustrialisation, industrialisation has permitted a limited number of emerging economies including Singapore, South Korea, and Taiwan to catch up. Similarly, by shifting workers from labour-intensive to capital-intensive production, China

15. Blinder (2006) similarly characterises the offshorability of jobs based on whether they can be delivered impersonally or whether they require face-to-face interaction and Leamer and Storper (2001) performs a similar characterisation based on the extent to which tasks are codifiable or whether they require tacit knowledge.

has more recently become a middle-income country. Because economic history suggests that countries entering the middle-income bracket subsequently experience stagnant growth, this phase is sometimes referred to as a middle-income trap.

One of the reasons why we see fewer countries escaping the middle-income trap is that emerging economies are increasingly experiencing premature deindustrialisation. As shown by Rodrik (2015), peak manufacturing employment has steadily declined among emerging economies over the course of the twentieth century. While the world's first industrial nation — the United Kingdom — saw a peak employment share in manufacturing of some 45 percent, manufacturing employment in modern emerging economies, such as Brazil and India, has typically peaked at below 15 percent (see Figure 6). A plausible explanation is that the automation of manufacturing processes today is increasingly cost-effective at lower wage levels. China, for example, has not only been the fastest growing market for industrial robots, but has also replaced the United States as the largest market for automation, underscored by the fact that automation was designated a new strategic area in the country's 12th Five Year Plan.

Figure 6. **Premature deindustrialisation**




*Notes*: Employment data is based on Timmer et al. (2014) and GDP per capita is obtained from Bolt and van Zanden (2014) and are measured in $1990GK. The year in which the manufacturing employment share peaked is given within parentheses and a fitted OLS regression line is also shown.

Some emerging economies have however also experienced declines in manufacturing output which cannot be explained by production processes being increasingly automated. Rodrik (2015) thus argues that globalisation provides a complementary explanation for countries experiencing premature deindustrialisation: as countries with a comparative disadvantage in manufacturing become exposed to international trade they start to import deindustrialisation. Crucially, while many twentieth century technologies, including the telephone, the container ship, and the computer, contributed to the surge in international trade by allowing companies to shift production to locations with an abundance of cheap labour, recent developments in robotics and additive manufacturing now allows firms in advanced economies to locate production closer to domestic markets in more fully automated factories. For example, despite a secular decline in its share of manufacturing employment, the US manufacturing output share has remained roughly constant. In other words, although the United States has not produced many new jobs in production it remains a competitive manufacturing location, as computer technologies provides an increasingly cheap substitute for workers. Even in middle-income countries,

such as China, industrial automation provides an increasingly cheap substitute for labour; recent estimates shows the payback period for industrial robots in China is now less than two years.[16]

Thus, in emerging and advanced economies alike, new technologies are shifting the composition of the workforce. In advanced economies, there is a concern over a slowdown in productivity and growing income disparities as workers reallocate to technologically stagnant sectors. Meanwhile, increasingly automated manufacturing processes make the transition of workers into low-skilled manufacturing a more unlikely growth model for future emerging economies, potentially requiring a shift from export-led to consumption-based growth in the developing world. As the process of deindustrialisation continues, the future of overall growth of productivity will depend on the extent to which new technologies can be implemented to increase productivity in the service sector. In the next section, we review how the expanding scope of automation may increase productivity beyond manufacturing in the future.

**Job Destruction: The Expanding Scope of Automation**

The boundaries between technologically progressive and technologically stagnant sectors of the economy have shifted over time and will inevitably continue to shift also in the future. Agriculture was long a technologically stagnant sector, absorbing most of the workforce across economies, but gradually witnessed substantial productivity gains following scientific advances and a pervasive mechanisation of production. In a similar manner, todays emerging technologies are likely to significantly increase productivity in a wide range of services.

In recent years, the scope of automation has expanded considerably. Aided by an increasing availability of big data and advances in Machine Learning – including Data Mining, Machine Vision, and Computational Statistics – a wide range of complex knowledge work has been transformed into well-defined and thus automatable problems. Health-care services, for example, increasingly draw upon advances in big data processing techniques to aid medical professionals. At the Memorial Sloan Kettering Cancer Centre, IBM's Watson computer is employed to diagnose diseases; drawing upon some 600,000 medical evidence reports and two million pages of text from medical journals, Watson can instantly match information on a patient's symptoms and genetics to deliver tailored treatment plans.[17] In a similar fashion, Google Translate not only provides real-time translation services that exploit the increased availability of digitalised translated texts, but also exploit advances in Machine Learning to allow its algorithms to improve accuracy over time. In addition, news services, such as Forbes and the LA Times, rely on sophisticated algorithms to generate corporate earnings reports as well as shorter summary pieces on earthquakes, homicides, and sports games.

At the centre of the big data revolution are the key enabling technologies of enhanced digital sensors, improved user interfaces, and the widespread diffusion of connected devices. Improvements in speech recognition, for example, allow mobile devices to respond directly to human voice commands, perhaps most widely known through Apple's Siri software. Yet, advances in natural language processing also promises to more fundamentally reshape entire service industries: call automation service provider SmartAction, for instance, is able to reduce costs by some 60-80 percent compared to conventional call centres. To aid the automation of more complex jobs, work activities are typically divided into tasks that lend themselves to computerisation and those that still require

16. See https://ir.citi.com/2pVaG3u3xb1xCK2Kj4f6gLnirSputFx3oVePA5AkT7jLzc5lLKckKg%3D%3D

17. MGI (2013). To encourage software developers to find other applications for the technology, IBM made Watson's programming interface publicly available two years ago to promote the development of a wider range of digital services drawing on its unique capabilities.

human inputs. Companies such as Work Fusion provide software that divides jobs into routine and non-routine activities, where the former are automated while the latter are outsourced through crowdfunding platforms to freelancers. Most interestingly, as the freelance workers perform the non-routine tasks, the software monitors them and gathers information on how they proceed to execute their tasks, so that over time the system is learning how to perform them.[18] Against the backdrop of such advances, available estimates suggest that computer technology could displace as many as 140 million knowledge workers worldwide, though such estimates are associated with a wide error margin.[19]

Big data technologies further exploit the massive amounts of information made available by cheaper and more advanced sensors, allowing engineers to overcome several barriers to robotic development. For example, the increased availability and improved resolution of 3D maps of road networks has been fundamental to the rapid development of autonomous vehicles. In a similar fashion, increasingly cheap and enhanced sensors are allowing industrial robots to become more flexible and mobile, thus bringing a wider range of non-routine tasks into the domains of robots. Perhaps the most widely known example is Rethink Robotic's Baxter. By simply guiding its compliant arms, Baxter can instantly be reprogrammed to perform tasks ranging from line loading and machine tending, to packaging and material handling. An increased flexibility of robots combined with advances in natural language processing similarly allow humanoids to perform work ranging from managing a hotel reception to tending to the elderly, aiding with tasks such as check-in or lifting patients from a bed to a wheelchair. Moreover, increasingly flexible robots can now also execute unstructured tasks in commercial cleaning and food preparation (Frey and Osborne, 2013). Taken together, while advances in big data coupled with sophisticated algorithms now permit the automation of an increasingly wide range of knowledge work, simultaneous advances in robotics is facilitating the replacement of human labour in an expanding set of manual tasks.

While the rapidly expanding scope of automation is likely to increase productivity, it may also constitute a watershed for OECD labour markets. According to estimates by Frey and Osborne (2013), 47 percent of the US workforce is susceptible to computerisation over the forthcoming decades, as a result of recent trends in technology, including jobs in production, transportation and logistics, services and sales, as well as a wide range of administrative support and office occupations (see Table 1).[20] While occupational employment statistics outside the United States are typically less detailed, these studies have been translated to a range of other OECD countries, suggesting that roughly 48 percent of jobs in Switzerland, 42 percent of jobs in Germany, and 35 percent of jobs in the United Kingdom, Denmark and Finland are highly susceptible to automation.[21] Furthermore, using a much cruder occupational classification, a study conducted by Bruegel (2014), found that 54 percent of EU jobs are at risk of automation, ranging from 47 percent in Sweden to 62 percent in Romania.

In the light of these developments, a key question is in which tasks human labour will retain a comparative advantage? Crucially, despite the rapidly expanding scope of automation, considerable engineering bottlenecks remain in Machine Learning and Mobile Robotics. Frey and Osborne (2013) identify three key bottlenecks that ultimately set the current boundaries for the application of

18. See the Guardian (2015).

19. MGI (2013)

20. A recent study by McKinsey (2015), which examines the feasibility of automating 2 000 work activities, similarly estimates that 45 percent of tasks undertaken by US workers are automatable with existing technology.

21. See Deloitte (2015a), ETLA (2014), Frey and Osborne (2014), and SSF (2014).

computer-controlled equipment: (i) creative intelligence; (ii) social intelligence; and (iii) perception and manipulation. Creative tasks are difficult to automate since it is challenging to reduce creativity to a set of explicit guidelines or rules. For example, while software can both compose novel pieces of art and music, it is extremely hard to teach an algorithm to distinguish between the emotionally powerful and the dreck, largely because most humans themselves are unable to define what makes something truly moving. In a similar way, social intelligence is difficult to computerise because our understanding of human interactions build on a tacit understanding of emotive content, which allow us to instantly adapt to changes in a person's facial expressions as well as different social and cultural cues and contexts. Thus, tasks that require assisting or caring for others, for example, remain challenging to automate, since they require real-time adaptation to human needs and emotions.[22] Finally, robots are still challenged to match the breadth and depth of human perception. Interestingly, humans perform most tasks that require perception or manipulation effortlessly, reflecting what computer scientists refer to as *Moravec's paradox*: "it is comparatively easy to make computers exhibit adult level performance on intelligence tests or playing checkers, and difficult or impossible to give them the skills of a one-year-old when it comes to perception and mobility".[23] In particular, while most humans can navigate unstructured environments with ease, the flexibility and perception of robots still largely limit them to operate in controlled and unchanging environments. Consider the mundane example of cleaning a hotel room: while it is relatively simple for a human to distinguish between a dirty and clean towel or to identify whether a bed is unmade, robots are challenged to reproduce even such basic levels of human perception. Thus, when it comes to tasks that require adaptation to an unstructured environment or physical flexibility, humans are likely to outperform robots for the foreseeable future.

Table 1. **Most and least likely jobs to be computerised**

| Occupation | Probability | Occupation | Probability |
|---|---|---|---|
| **Telemarketers** | 99,0% | Recreational Therapists | 0,3% |
| **Title Examiners Abstractors and Searchers** | 99,0% | First-Line Supervisors of Mechanics Installers and Repairers | 0,3% |
| **Sewers Hand** | 99,0% | Emergency Management Directors | 0,3% |
| **Insurance Underwriters** | 98,9% | Mental Health and Substance Abuse Social Workers | 0,3% |
| **Mathematical Technicians** | 98,9% | Audiologists | 0,3% |
| **Watch Repairers** | 98,8% | Occupational Therapists | 0,3% |
| **Cargo and Freight Agents** | 98,7% | Orthotists and Prosthetists | 0,4% |
| **Tax Preparers** | 98,7% | Healthcare Social Workers | 0,4% |
| **Photographic Process Workers and Processing Machine Operators** | 98,7% | Oral and Maxillofacial Surgeons | 0,4% |
| **New Accounts Clerks** | 98,7% | First-Line Supervisors of Fire Fighting and Prevention Workers | 0,4% |
| **Library Technicians** | 98,6% | Dietitians and Nutritionists | 0,4% |
| **Data Entry Keyers** | 98,5% | Lodging Managers | 0,4% |
| **Timing Device Assemblers and Adjusters** | 98,5% | Choreographers | 0,4% |

22. A widely cited example of the expanding capabilities of computers in reproducing human social interaction is the fact that a software "chatterbot" recently passed the Turing Test, which involves programming a computer to be indistinguishable from a human in a textual chat conversation. Although a remarkable feat, this example at the same time clearly demonstrates that tasks that require more advanced forms of interpersonal skills remain far outside of the boundaries of current capabilities of computer technology.

23. Moravec (1988, p.15).

| Occupation | Probability | Occupation | Probability |
|---|---|---|---|
| **Insurance Claims and Policy Processing Clerks** | 98,4% | Sales Engineers | 0,4% |
| **Brokerage Clerks** | 98,4% | Physicians and Surgeons | 0,4% |
| **Order Clerks** | 98,4% | Instructional Coordinators | 0,4% |
| **Loan Officers** | 98,4% | Psychologists All Other | 0,4% |
| **Insurance Appraisers Auto Damage** | 98,3% | First-Line Supervisors of Police and Detectives | 0,4% |
| **Umpires Referees and Other Sports Officials** | 98,3% | Dentists General | 0,4% |
| **Tellers** | 98,3% | Elementary School Teachers Except Special Education | 0,4% |
| **Etchers and Engravers** | 98,2% | Medical Scientists Except Epidemiologists | 0,5% |
| **Packaging and Filling Machine Operators and Tenders** | 98,0% | Education Administrators Elementary and Secondary School | 0,5% |
| **Procurement Clerks** | 98,0% | Podiatrists | 0,5% |
| **Shipping Receiving and Traffic Clerks** | 97,9% | Clinical Counseling and School Psychologists | 0,5% |
| **Milling and Planing Machine Setters Operators and Tenders Metal and Plastic** | 97,9% | Mental Health Counselors | 0,5% |
| **Credit Analysts** | 97,9% | Fabric and Apparel Patternmakers | 0,5% |
| **Parts Salespersons** | 97,8% | Set and Exhibit Designers | 0,5% |
| **Claims Adjusters Examiners and Investigators** | 97,8% | Human Resources Managers | 0,5% |
| **Driver/Sales Workers** | 97,8% | Recreation Workers | 0,6% |
| **Radio Operators** | 97,7% | Training and Development Managers | 0,6% |

*Notes*: This table report the occupations with the highest and lowest probabilities of computerisation based on the methodology developed in Frey and Osborne (2013).

An important implication of the estimates of Frey and Osborne (2013) is that the pattern of SBTC is likely to continue over the forthcoming decades: jobs that are typically performed by college-educated workers are substantially less likely to be susceptible to automation (see Figure 11). Nevertheless, as the potential scope of automation is now expanding beyond routine tasks, RBTC is likely to come to halt: while the automation of routine tasks has been associated with a decline in middle-skilled jobs, the estimates of Frey and Osborne (2013) suggests that low-skill jobs are now becoming increasingly susceptible to automation. Recent empirical evidence lends some support to this prediction: analysing the economic impact of industrial robots across 17 OECD economies between 1993 and 2007, Graetz and Michaels (2015) find that while the implementation of robots increased both labour productivity and value added it reduced hours worked primarily for low-skilled workers, with less pronounced declines for workers with middling skills. Furthermore, a recent study by Deloitte (2015b), applying the approach of Frey and Osborne (2013) to the United Kingdom, shows that occupations with a high susceptibility to automation experienced sharp employment declines between 2010 and 2015, while jobs that are less exposed experienced rapid growth. Looking forward, the increased automatability may thus exacerbate already pronounced wage inequality and further contribute to reductions in the labour share of income.

### Job Creation: New Tasks, Occupations, and Industries

While new technologies have displaced workers in a wide range of jobs, they have equally created new tasks, occupations, and industries. A growing literature shows that as technology makes some tasks redundant, it raises the demand for workers in others, leading the task composition of occupations to shift in response. Over the course of the twentieth century, for example, jobs have become increasingly interactive as a result of technological change. Examining the task composition of US employment between 1880 and 2000, Michaels et al. (2013) show that tasks involving communication, interpersonal activities, and thought have become more prominent across occupations and industries, as well as increasingly geographically concentrated to larger and denser metropolitan

areas. By isolating the changing occurrence of 3,000 verbs in official task descriptions of more than 12,000 occupations, they find that while the tasks most concentrated in late-nineteenth century cities were "braid", "sew", and "thread", work in urban areas today revolves around tasks that require workers to "analyse", "advise", and "report".[24] Their findings further suggest that shifts in the task composition of employment were driven by the adoption of new technology: improvements in communications infrastructure, such as the diffusion of the telephone in the early twentieth century, significantly increased the interactiveness of jobs.

The task composition of occupations has seemingly also changed in response to the arrival of digital technology. The diffusion of online platforms, for example, means that jobs can be subdivided and unbundled, allowing smaller projects or tasks to be outsourced to freelance workers. According to work by Tambe and Hitt (2010) some 40 percent of US high-tech firms offshore tasks, while retaining work that requires face-to-face contact or physical proximity onshore (Blinder, 2009), implying a growing demand for interpersonal skills as a result.[25] Spitz-Oener (2006) further documents that the task composition of jobs has become increasingly complex since the 1980s, and especially in occupations that underwent significant computerisation. These findings are also consistent with those of Autor et al. (2003) and Berger and Frey (2016b), showing that workers in industries and occupations that underwent rapid computerisation increasingly performed analytic and interactive work, as routine tasks were automated away. More recent qualitative evidence further mirrors this tendency: Table 2 presents examples of new tasks that have emerged in the past two years, suggesting that new tasks often are related to the arrival of digital technology directly (e.g., developing software for aerospace systems) and tend to require interactive and analytical skills (e.g., present result of statistical analyses to stakeholders).

Table 2. **Examples of new tasks**

| Occupation | New Task | Occupation | New Task |
|---|---|---|---|
| **Aerospace Engineers** | Develop software for aerospace systems. | Public Relations Specialists | Post and update content on the company's website and social media outlets. |
| **Fitness and Wellness Coordinators** | Evaluate fitness and wellness programs to determine their effectiveness. | Soil and Plant Scientists | Conduct experiments to investigate the underlying mechanisms involved in plant growth and plant responses to the environment. |
| **Mapping Technicians** | Prepare cost estimates for mapping projects. | Statistical Assistants | Present results of statistical analyses to stakeholders. |

*Source*: O*NET, https://www.onetcenter.org/supplemental.html.

24. Furthermore, the examples of new tasks listed in Table 2 similarly underline the role of more interactive work activities, as the task descriptions involve verbs such as "develop", "evaluate", and "present".

25. Sophisticated software now also allows firms to sub-divide more complex work into routine and non-routine tasks with the latter being outsourced to freelance workers (see previous section).

Meanwhile, digital technology has created entirely new occupations and industries. Building on work by Lin (2011), examining new job titles emerging as a result of technological change, Berger and Frey (2016b) show that new jobs mainly have emerged in occupations and industries that extensively adopted computers since the 1980s. Throughout the 1980s and 1990s, most new job titles were also directly related to computer technology, including the ones of database administration or software engineering. The emergence of new technology-related occupations of the twenty-first century is similarly evident from Table 3, showing that a wide range of job titles are directly associated with technological advances in general (e.g., Fuel Cell Engineers and Nanosystems Engineers), and computer technology in particular (e.g., GIS Information Scientists and Search Marketing Strategists). In addition, work by Berger and Frey (2016a) show that out of 71 new industry titles that emerged in official classifications between 2000 and 2010, 51 were directly associated with digital technologies, including online auctions, web design, and video and audio streaming. In line with popular perceptions, their estimates further suggests that new technology industries mainly have created employment opportunities for highly skilled workers: jobs in new industries are typically well-paid – with workers earning more than twice than the US median wage on average – and generally require workers to have at least a bachelor's degree, preferably in a STEM field.

Table 3. **Examples of new and emerging occupations**

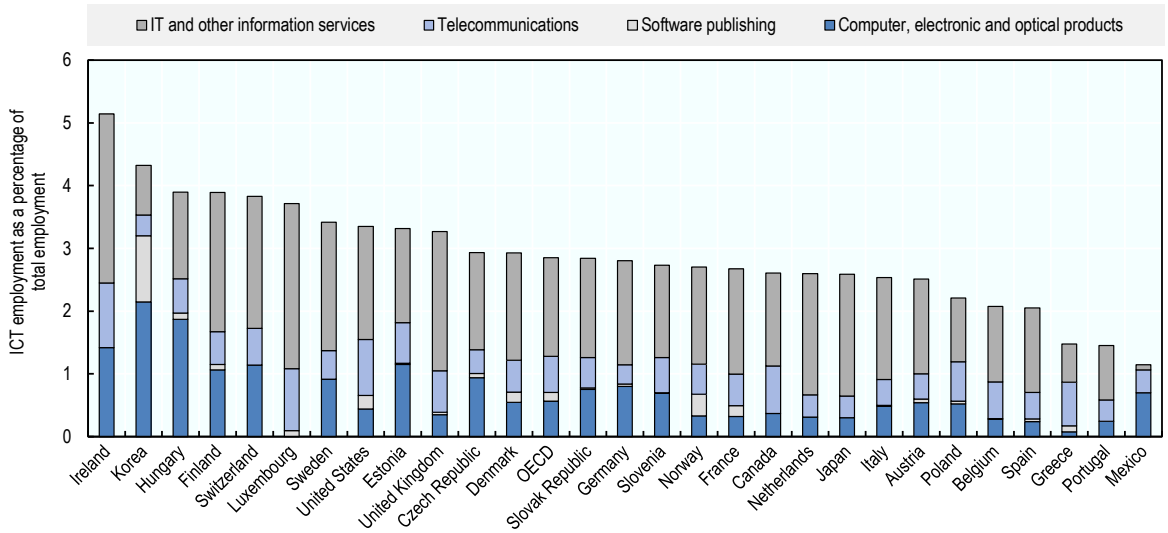
| | |
|---|---|
| Adapted Physical Education Specialists | **Fuel Cell Engineers** |
| Advanced Practice Psychiatric Nurses | **Geospatial Information Scientists and Technologists** |
| Baristas | **Industrial Ecologists** |
| Biochemical Engineers | **Microsystems Engineers** |
| Bioinformatics Scientists | **Nanosystems Engineers** |
| Biostatisticians | **Radio Frequency Identification Device Specialists** |
| Climate Change Analysts | **Search Marketing Strategists** |
| Database Architects | **Solar Energy Systems Engineers** |

*Source*: O*NET, https://www.onetcenter.org/supplemental.html.

Although it is evident that new technologies have created a wide range of new occupations and industries, these are unlikely to have had a substantial impact on the aggregate demand for skills. For example, while the ICT sector itself is often held to be an important engine of job creation, it is still negligible as a share of total employment.[26] In 2013, some 14.4 million OECD workers were employed in the ICT sector and associated sub-sectors, constituting slightly less than 3 percent of total employment (see Figure 7). While information services absorb most of these workers, sub-sectors such as software and telecommunications contribute significantly less to total ICT employment. OECD countries, however, exhibit considerable differences in sectorial specialisation patterns, arguably reflecting different comparative advantages. Furthermore, in the OECD region as a whole, the ICT sector's contribution to total employment has varied significantly over time (Figure 8): between a quarter and half of the aggregate job losses following the Dot-Com bubble originated from the ICT sector, with a similar negative contribution in the aftermath of Great Recession. More recently, however, the ICT sector has seen a brief resurgence in job creation. Between 2011 and 2012, ICT jobs contributed some 4 percent to total job growth in the OECD, accelerating to some 22 percent in 2013 (OECD 2015b). Yet, despite this recent growth surge, it has yet to surpass its peak employment of the early 2000s (OECD 2013b).

26. Atasoy (2013), for example, provides evidence on the overall impact of the spread of broadband services, showing that access leads to increases in employment rates and labour force growth.

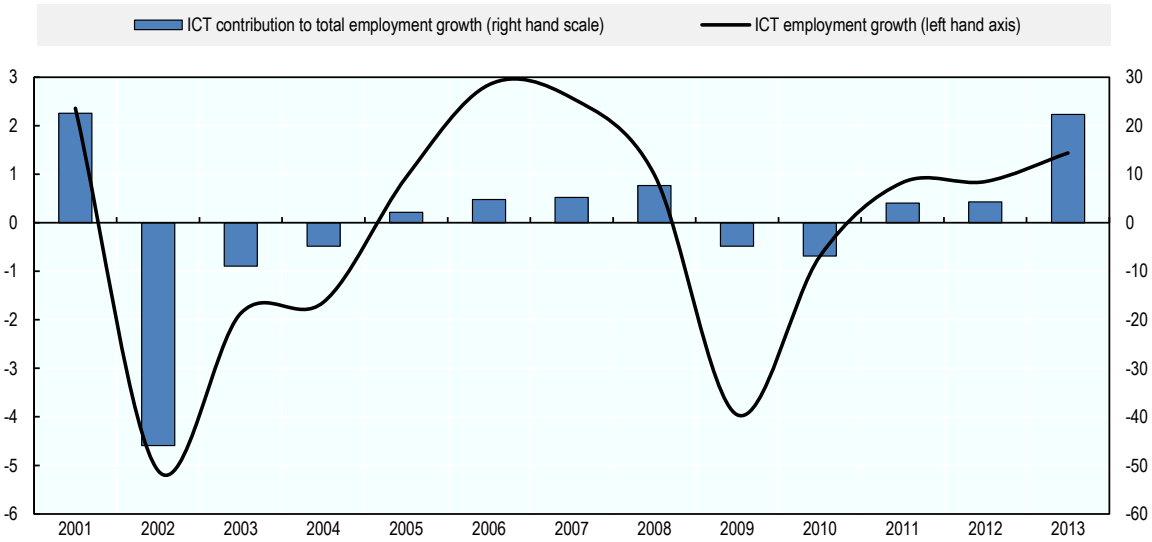
Figure 7. **Employment in ICT sector and sub-sectors OECD, 2013**




*Notes*: This figure report employment shares in the ICT sector and sub-sectors in 2013 (defined as the sum of industries ISIC rev.4; 26, 582, 61 and 62-63) based on the OECD Key ICT Indicators, http://oecd.org/sti/ieconomy/oecdkeyictindicators.htm. Due to varying data availability, employment data for some countries refer to other years.

*Source:* OECD (2015a).

Figure 8. **Contribution of ICT sector to employment growth in the OECD**




*Notes*: This figure reports the aggregate contribution of the ICT sector to total employment growth for 27 OECD countries for which data is available from OECD (2015a). Data is based on the OECD National Accounts database (ISIC rev.4) and national sources.

*Source*: OECD, (2015a).

In addition, there is evidence suggesting that new job creation associated with arrival of new technologies has stagnated since the computer revolution of the 1980s. A recent study by Lin (2011) documents that while some 8.2 percent of US workers were observed in new types of jobs in 1990,

that share had decreased to some 4.4 percent by 2000. Estimates in Berger and Frey (2016a) further suggest that less than 0.5 percent of US workers are employed in new technology-related industries that have been created in the 2000s. Similar studies of other countries document results consistent with these observations: in the United Kingdom, for example, a modest 6 percent of workers were employed in jobs created since the 1990s in 2014 (Frey, 2015). A slowdown in new job creation is moreover broadly consistent with studies by Haltiwanger et al. (2014) showing that business dynamism has declined in technology sectors in the 2000s. Although some comparability issues plague these numbers, they are fuelling a growing concern that digital technology is not creating employment opportunities for ordinary workers to the same extent that the major technologies, such as the automobile or the semiconductor, once did in the twentieth century.[27] Nevertheless, job creation in the technology sector has important spillover effects onto other sectors, as it creates additional demand for workers in the services sector. In a recent study, Moretti (2010) estimates that for each high-tech job created, in industries such as Computing Equipment or Electrical Machinery, some 4.9 additional jobs are created for lawyers, taxi drivers, and waiters in the local economy.

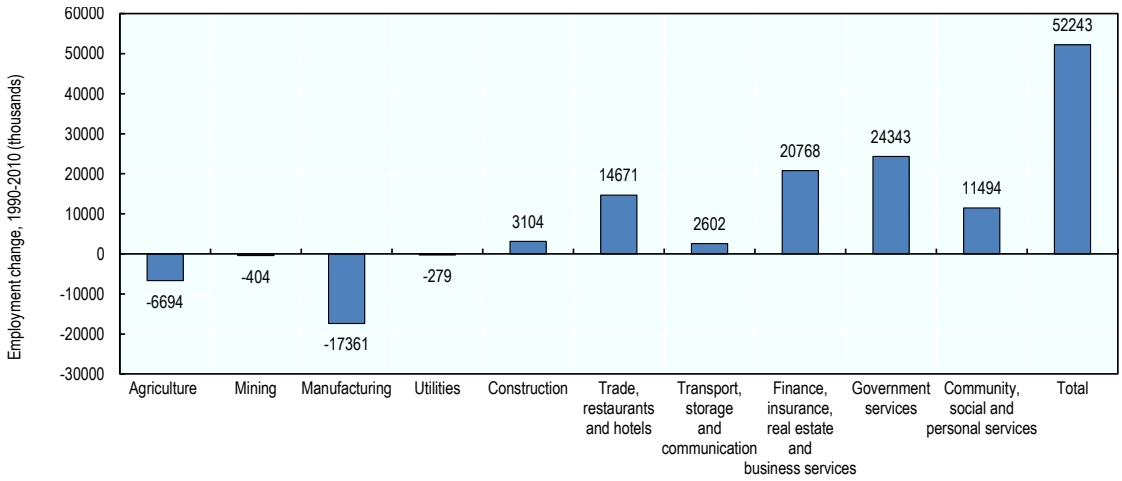
As technology sectors have generated few new jobs, recent job growth among OECD countries has originated in non-technology sectors. Since the early 1990s, a staggering 98 percent of employment growth in United States has taken place in sectors producing non-tradable outputs; some 40 percent of this increase was due to expansions in government services and health care, with significant contributions also from the accommodation, food, and retail industry (Spence and Hlatshwayo 2012). Over the same period, the tradable sector added a meagre 0.6 million jobs, less than a 2 percent growth relative to the total employment in 1990. Moreover, job creation in the tradable sector is highly concentrated to skilled sectors, such as engineering, finance, and computer design, while job losses were concentrated in less skill-intensive jobs in the auto industry, agriculture, and chemicals. In contrast to low job creation, however, the tradable sector experienced more than four times more rapid productivity growth (measured as value added per worker), which implies that job creation and productivity took place in different parts of the economy. Evidence for the OECD region as a whole reveals a similar tendency: as documented in Figure 9. the employment increase in relatively skilled tradable professional services – including finance, insurance and business services – is smaller than the sharp declines of employment in manufacturing and agriculture combined. Meanwhile, non-tradable sectors, including restaurants, hotels, transportation government, and various community and personal services, account for the bulk of employment growth between 1990 and 2010.

Thus, while new job creation in technology industries has seemingly experienced a secular decline since the computer revolution of the 1980s, technology-producing manufacturing jobs in the tradable sector has been replaced by the rise of relatively skilled technology-using professional services. At the same time, job creation in technological stagnant sectors of the economy has rapidly expanded, potentially contributing to a slowdown in the demand for college-educated workers: for example, Beaudry et al. (2013) document a decline in the demand for skill in the United States over the 2000s, even as the supply of workers with a college degree continued to grow. In addition, they find that high-skilled workers gradually moved down the occupational ladder, taking on jobs that were previously performed by low-skilled workers, in turn pushing low-skilled workers further down the occupational ladder, or even out of the labour force. While these findings arguably contrasts the ones of Berger and Frey (2016a), suggesting that technological change was skill-biased throughout the 2000s, the modest employment contribution of the digital revolution over this period is likely to have a

27. Lee (2015) calculates that employment in automobiles grew more than 700 percent faster than aggregate manufacturing employment between 1904 and 1929, while growth in the semiconductor industry outpaced rest of manufacturing by some 121 percent between 1958 and 1987.

negligible impact on the demand for skills. Meanwhile, however, pervasive evidence provided in this section suggests that that the arrival of digital technologies has had a substantial impact on the task composition of jobs, in turn shifting the demand for skills, implying that the demand for college-educated workers does not adequately reflect the demand for new skills. We next proceed to discussing skill demands associated with the changing composition of the workforce.

Figure 9. **Employment changes in selected OECD countries, 1990-2010**

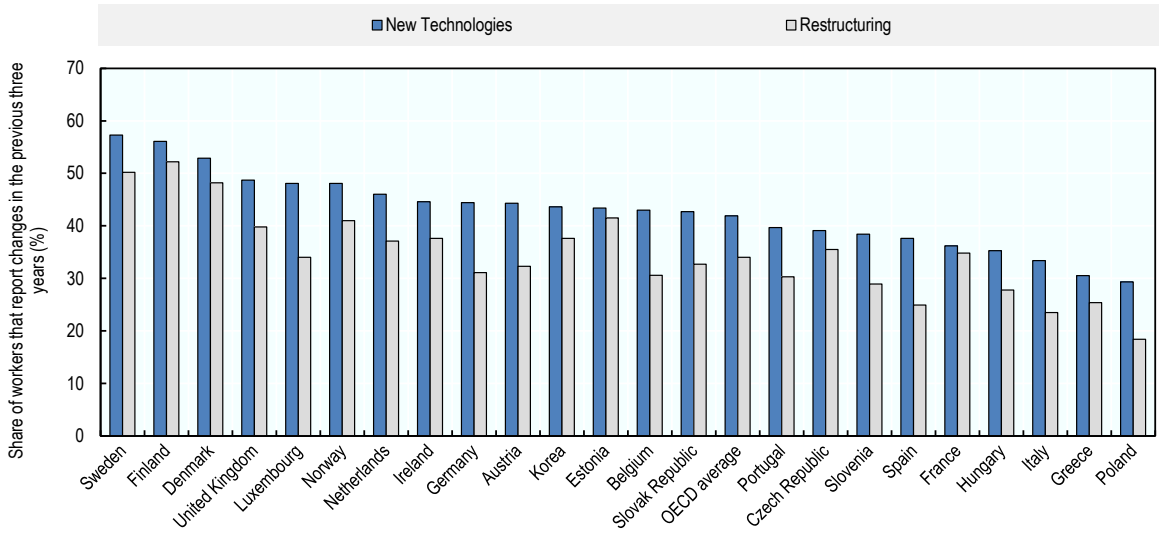



*Notes*: This figure reports employment changes across 10 sectors in 12 OECD countries (Denmark, Japan, Korea, Chile, Mexico, United States, Spain, France, the United Kingdom, Italy, the Netherlands, and Sweden) between 1990 and 2010, based on data provided by the GGDC 10-Sector Database, http://www.rug.nl/research/ggdc/data/10-sector-database.

## Skill Requirements in the Digital Economy

Although digital technologies have not created many new jobs directly, their impact on the demand for skills across occupations and industries has been substantial. As firms continue to reorganise production to increase productivity and accommodate the arrival of new technologies, the workplace will experience rapid change. Indeed, some 42 percent of OECD workers are employed in firms that have introduced new technologies that have changed work routines or skill requirements in past years (see Figure 10), although considerable differences in technology adoption exist across countries: while more than half of Scandinavian workers reported that new technologies had been implemented at their workplace, less than one in three workers in Poland and Turkey had experienced technological change. Faster technology adoption will thus have implications for skill demand across the OECD: as technology continues to transform a wide range of jobs, workers will have to acquire generic skills such as the ability to learn and self-management to adapt to a rapidly changing labour market (Caroli and Van Reenen 2001; Green, 2012 and OECD 2013a).

Figure 10. **Technological progress is changing workplaces in the OECD**




*Notes*: This figure reports the percentage of workers in the OECD's PIAAC study that reported that the introduction of new processes or technologies and structural changes, defined as restructuring or reorganisation, in the previous three years had affected their work environment.

*Source:* OECD (2013a).

As described in the previous section, digital technology is projected to make inroads into a wider range of jobs in the forthcoming decades, as advances in Machine Learning coupled with an increased availability of big data permit the automation of a wider range of work. However, although computer equipment is becoming increasingly capable of performing more complex tasks, jobs that involve creativity and social intelligence are likely to persist (Frey and Osborne 2013), suggesting that these are two broad skillsets that will increase in relative importance also in the future. In particular, the growing importance of high-level cognitive and interpersonal skills has already been emphasised by the OECD (2013), arguing that an increasing automation of manufacturing and low-skill service jobs will further reduce the relative demand for routine cognitive and manual skills. However, the growing importance of creative and social skills is likely to differentially affect jobs across the skill spectrum: for example, as newspapers can now use algorithms to produce standardised news stories journalists are likely to shift towards writing that requires human-level creative skills, at the same time as many expanding low-skill service occupations increasingly require workers to have social skills such as service orientation and social perceptiveness (see Table 3).

The emergence of new jobs also drives skill demand as these embody the evolving skill complementarities of new technologies. After the introduction of the PC in the 1980s, for example, new jobs became increasingly abstract in nature, raising the demand for analytical, communicative, and problem-solving skills (Berger and Frey, 2016b).[28] Since educated workers have a comparative advantage in performing such tasks, these shifts at the same time corresponded to an increase in educational requirements of new work (Lin, 2011), also reflecting the fact that skill upgrading was more rapid in computer-intensive industries (Autor et al., 1998). The rising skill-intensity of new work is further suggested by the fact that workers in new technology-related industries are often required to

28. Bartel et al. (2007) similarly show, using firm-level data, that the adoption of IT-enhanced equipment led to an increased importance of technical and problem-solving skills among affected workers, with supplementary changes in human resource practices to support these skills.

have at least a bachelor's degree, preferably in a STEM field (Berger and Frey 2016a). Table 4 presents representative skill requirements in new and emerging occupations in high growth industries, further showing that new jobs often require complex problem-solving skills, high-level technical skills such as programming, or a broader range of social skills such as management, instruction, and service skills.

Table 4. **Examples of skills required in New and Emerging occupations**

| Skill | Description | Skill | Description |
|---|---|---|---|
| Complex Problem Solving | Identifying complex problems and reviewing related information to develop and evaluate options and implement solutions. | Programming | Writing computer programs for various purposes. |
| Critical Thinking | Using logic and reasoning to identify the strengths and weaknesses of alternative solutions, conclusions or approaches to problems. | Social Perceptiveness | Being aware of others' reactions and understanding why they react as they do. |
| Active Learning | Understanding the implications of new information for both current and future problem-solving and decision-making. | Management of Personnel Resources | Motivating, developing, and directing people as they work, identifying the best people for the job. |
| Judgment and Decision Making | Considering the relative costs and benefits of potential actions to choose the most appropriate one. | Service Orientation | Actively looking for ways to help people. |
| Instructing | Teaching others how to do something. | Systems Evaluation | Identifying measures or indicators of system performance and the actions needed to improve or correct performance, relative to the goals of the system. |

*Source*: O*NET, https://www.onetcenter.org/supplemental.html.

In addition, most occupations now require workers to have digital skills, ranging from basic competencies such data entry and processing, to extensive knowledge of circuit boards, processors, chips, including applications and programming. To gauge the demand for basic user skills, we examine on-the-job use of digital technology by exploring data from O*NET that maintains information on IT tools and technologies used within more than 900 occupations.[29] Remarkably, there are only two occupations that *do not* use IT technology – Dishwashers and Food Cooking Machine Operators and Tenders – suggesting that digital skills are already crucial for the vast majority of workers. In a similar way, evidence on the share of workers that use an Internet-connected computer on the job suggest that digital skills are essential to a considerable share of OECD workers: as many as 98 percent of workers in Iceland and about half of workers in Germany, France, and the United Kingdom use an Internet-connected computer at work (OECD 2013). In addition, recent estimates from the European Commission suggest that some 90 percent of workers in accountancy, engineering, and medicine will be required to have basic digital skills in the near future. Thus, as digital technology increasingly becomes an integral part of the daily operations of firms in a wider range of industries, basic digital skills will be a prerequisite for nearly all employees.

29. According to O*NET, this data "provides information on tools, information technology, software, equipment, and machines that workers need to perform successfully on the job. The information is comprehensive, but not exhaustive. Emphasis is placed on cutting edge technologies and emerging workplace practices."

In sum, as reflected in the skill demands of new and emerging occupations, as well as the recent expansion of the ICT sector, both advanced user skills and digital specialist skills are increasingly a requirement. In particular, workers are increasingly required to have additional skills in addition to ICT proficiency, as reflected in the fact that an above-median use of ICT skills on the job is also associated with a considerably higher use of literacy and numeracy skills (OECD 2013). Such "skill-use clusters" are becoming increasingly important for advanced ICT users; in the Slovak Republic, for example, some 25 percent of workers fall in the high-use category of combined ICT and problem-solving skills, while nearly one in five Czech, Korean, and Swedish workers are required to use ICT in combination with reading and writing skills (OECD 2013).[30] Against the background of the trends described, a particular skill-use cluster that is likely to increase in demand are *fusion skills* - combinations of business, entrepreneurial and technical skills - that will be required to transform technological advances into new businesses.

## Challenges for Policy

### *Inequality, Skill Shortages, and Social Mobility*

In tandem with a widening of the wage distribution (due to SBTC) and the demise of a wide range of middle-skill work (due to RBTC), as described in section describing labour market trends, most OECD have experienced increases in income inequality. Despite these trends, substantial variation in inequality exists across the OECD member states. Importantly, such cross-country differences in inequality are intimately associated with skills in two ways. First, differences in returns to skills shape inequality directly by determining the differential returns throughout the skill distribution. Secondly, for any given level of skill returns, the distribution of skills in the workforce is a key determinant of the distribution of wages; a more even distribution of skills will result in low levels of inequality, whereas a concentration of skills will result in a more unequal distribution of income. Indeed, countries in which skills are highly rewarded in the labour market and/or where skills are more unequally distributed among workers exhibit higher levels of wage inequality (OECD, 2013a). Addressing an uneven distribution of skills is thus a key for countries seeking to reduce wage inequality, not least since as much as 75 percent of inequality observed in any given year reflects permanent factors such as differences in skill demands (OECD, 2015a).

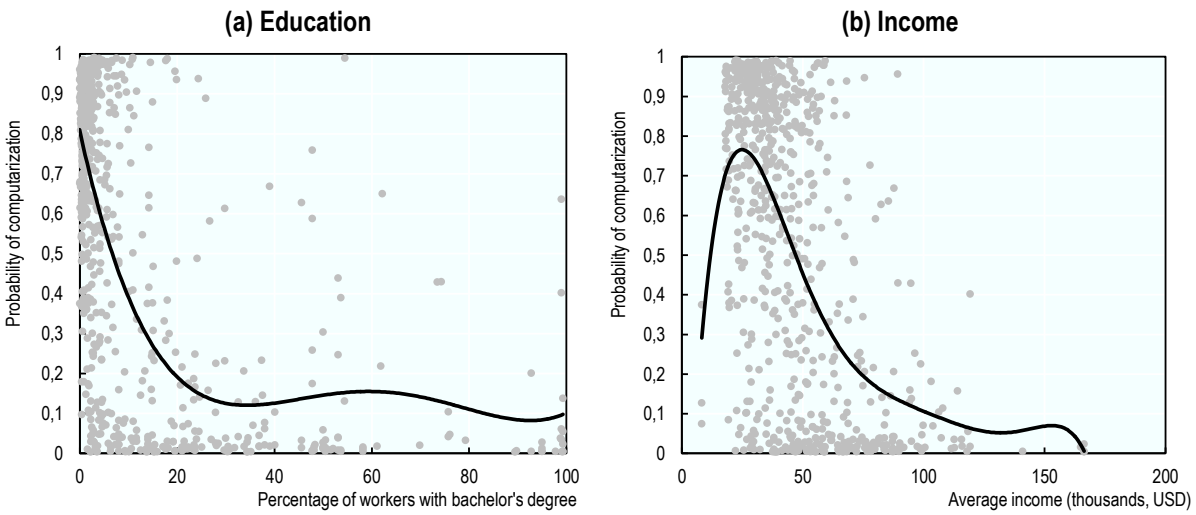
As the capabilities of digital technology expand into a wider range of human skill domains, tackling mismatches that arise between the skills of displaced workers and the skill demands in emerging jobs is another challenge to avoid further growing inequalities. Over the next decades, technology's impact is likely to shift to substitute mainly for low-skill workers, including those currently employed in simpler service jobs: Figure 11 shows a clear negative link between the average educational attainment and the likelihood that an occupation is feasible to automate (Frey and Osborne, 2013).[31] As the adverse impacts of technology will increasingly affect workers at the bottom end of the skill distribution, there is a growing concern that the economic opportunities of already disadvantaged workers will become even more constrained. A central challenge for these workers will be to acquire skills that allow them to transition into new types of meaningful employment opportunities. In particular, workers should strive to develop skills such as assisting and caring for

30. Note that high-use categories are defined based on within-country distributions of skill indicators, which complicates a direct cross-country comparison.

31. Note that the three outlier occupations in the bottom left of Figure 11b, with low average incomes and a low probability of computerisation are Actors, Dancers, and Musicians and Singers, which reflect three arguably creative occupations with well-known low average returns.

others, creativity, or persuasion-skills that are likely to remain resilient in the face of further technological advances.

Figure 11. **Computerisation will mainly affect low-skill and low-income workers**



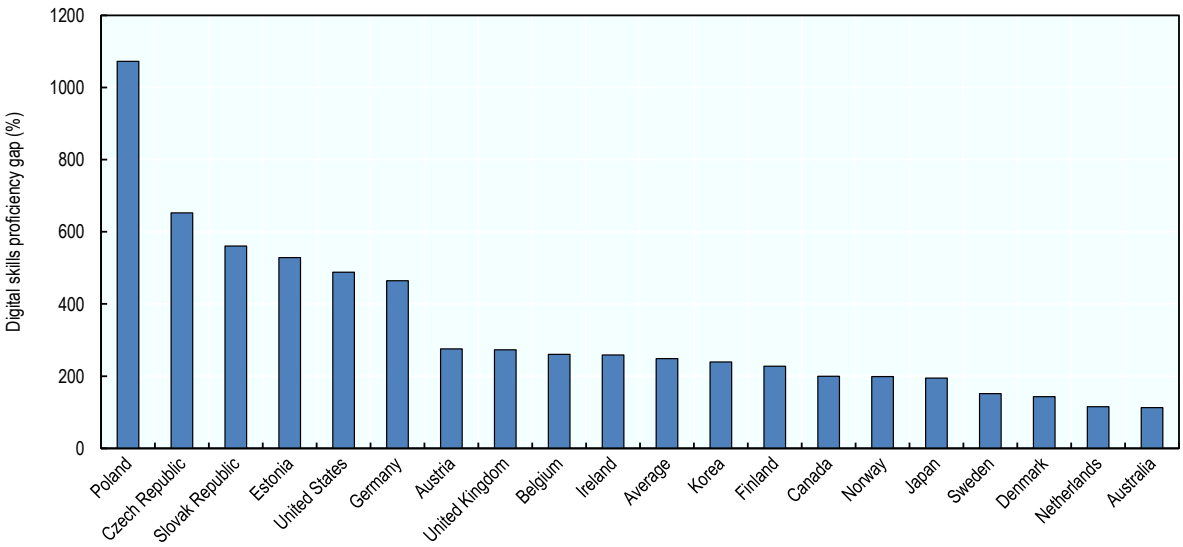

*Notes*: These figures show the probability of computerisation across 702 US occupations based on data in Frey and Osborne (2013) and the percentage of workers with a bachelor's degree and their average income by occupation. In each figure, a fifth degree polynomial is also shown.

*Source*: Frey and Osborne (2013).

At the same time as creative and interpersonal skills are growing in importance, digital skills will become mandatory for the vast majority of workers. Yet, a shortage of digital skills already exists in many parts of the OECD. In Italy, Korea, and Spain, for example, more than 23 percent of workers lack the skills needed to use simple ICT tools and less than one in ten adults exhibit the highest level of proficiency at solving problems in technology-intensive environments (OECD, 2013a). While investing in skills upgrading is thus crucial to raise the employability and productivity of many workers, better use can also be made of existing skills. Across the countries surveyed in the OECD's PIAAC study, for example, 21 percent of workers report that they are overqualified for their job, while 13 percent report that they are underqualified (OECD, 2013a). Finding ways to reduce mismatches between worker's skills proficiency and the actual skills they use in their job can provide a complementary lever to eliminate skill bottlenecks.

Although a focus on skill development is particularly important to enable disadvantaged workers to climb the jobs ladder, initiatives to upgrade the skills of the workforce would also serve to reduce wage gaps between socio-demographic groups. For example, about half of the gender wage gap among the countries examined in the PIAAC study is accounted for by differences in the use of problem-solving skills on the job, while some 70 percent of the gap between native and foreign workers reflects differences in skills (OECD, 2015a). As emphasised by the OECD (2013b), differences in digital skills further amplify already existing skill disparities across socio-economic, gender, and age groups: students from lower socio-economic backgrounds have lower digital proficiency, men use ICT more intensively than women at a young age, and older workers use ICT much less than younger workers. Bridging these digital divides would contribute to equalizing the distribution of skills in the workforce, thus dampening further increases in inequality.

Figure 12. **Differences in digital skills by level of parental education**




*Notes*: This figure reports differences in digital proficiency for adults with at least one parent attaining tertiary education relative to adults with no parent attaining upper secondary education. Digital proficiency is measured as the percentage of adults who score at Level 2 or 3 in problem solving in technology-rich environments in the OECD's PIAAC survey.

*Source:* OECD (2013a).

A particular concern is that as countries become more unequal, opportunities for economic advancement also become more circumscribed. Across OECD countries there is indeed a positive correlation between levels of inequality and intergenerational persistence in income, a relationship that economists often refer to as the "Great Gatsby" curve (e.g., Corak, 2013). Again, cross-country differences in the returns to skill play an important role to understand this relationship, due to the fact that parental education is a strong determinant of a child's educational attainment (Reardon, 2011). The OECD's PIAAC study, for example, provides clear evidence that a socioeconomically disadvantaged background is associated with substantially lower skills proficiency in adulthood (see Figure 12), further confirming the empirical importance of the intergenerational transmission of human capital. In a country with high returns to skill, children born to better educated parents will therefore on average both attain higher levels of education and enjoy greater returns to this investment (Autor, 2014). Further evidence on a link between educational investments and intergenerational mobility is provided by Chetty et al. (2014), showing that places that provide higher quality education also exhibit more upward mobility.

Thus, investments in improving the skills of the workforce are essential not only to revive faltering productivity growth in the OECD, but also to mitigate further unwanted increases in wage inequality while improving the economic opportunities for workers. As emphasised by Autor (2014), policies that are most effective at raising productivity, mitigating unwanted increases in inequality, while expanding economic opportunity are those that focus on ensuring broad access to high quality education for the vast majority of workers.

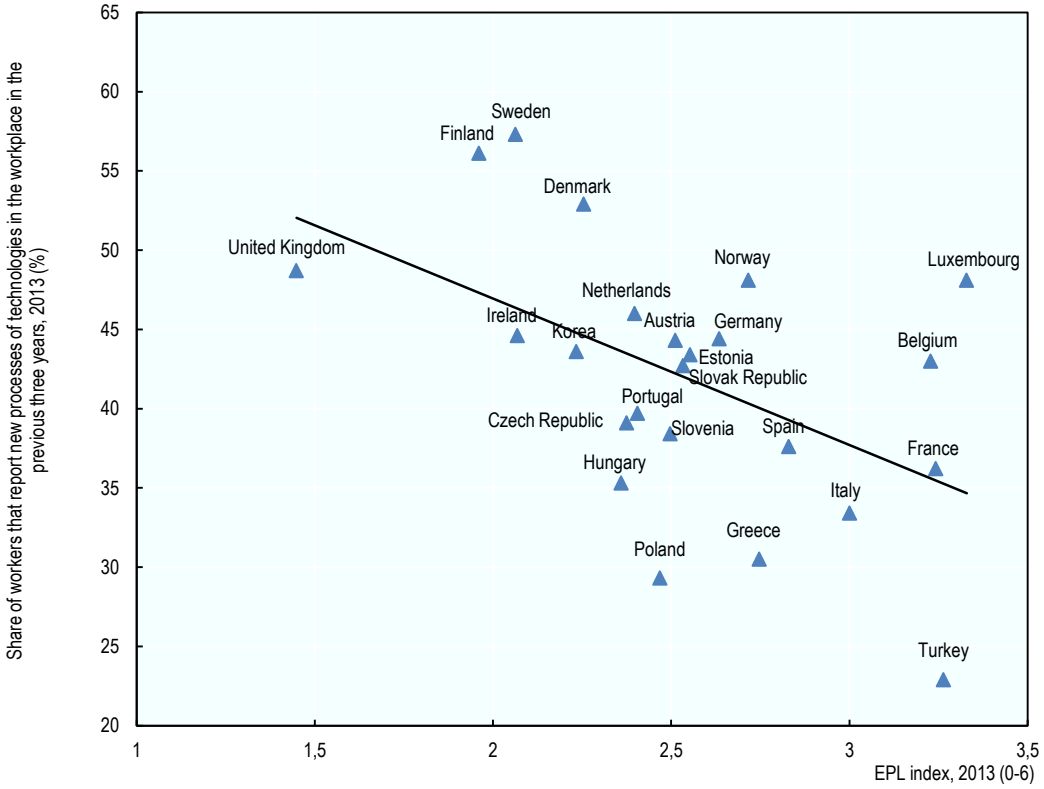
***Institutions and Technology Adoption: Cross-Country Differences***

While relevant skills are critical for the adoption of new technology, institutional factors also matter. For example, an influential study by Caselli and Coleman (2001) document those cross-country differences in computer adoption can be accounted for by a number of factors, including differences in human capital levels, trade openness vis-à-vis the OECD, and property rights protection. Furthermore, the same way institutional quality promotes technology adoption, dysfunctional institutions may impede technological progress. Comin and Hobijn (2009), for example, show that lobbying efforts by incumbents slow down the diffusion of new technologies: technologies with a predecessor diffuse more slowly than those without one in countries where the legislative authorities have more flexibility, but also in countries with a non-democratic effective executive or those ruled by a military regime. Similarly, the World Bank (2016) reports, that their digital technology projects have a higher likelihood of succeeding in countries with good institutions.

Institutional arrangements are further likely to matter the most in times of rapid technological progress, as it requires firms to be able to rapidly adapt organisational structures and freely experiment with new products and services. This idea was recently put forward by Crafts and Toniolo (2010), arguing that while more strict regulation did not hamper growth during the Post-War period, it has impeded productivity since the advent of the computer revolution. For example, while the US economy experienced productivity growth revival during the late-1990s, many European countries saw productivity growth falter. Most explanations for the productivity divergence between the two continents emphasise the role of relatively rapid ICT adoption in the United States, enabled by its relatively low regulatory barriers (e.g., van Ark, 2014).[32] Indeed, evidence suggests that a higher degree of product market regulation deters ICT investments (Conway et al., 2006), and leads to a smaller contribution of ICT services to productivity growth (Nicoletti and Scarpetta, 2005). In particular, the United States stands out in terms of its low levels of employment protection: in the 1970s, at the dawn of the computer revolution, the United States scored 0.5 on the 0-10 employment protection scale of Nickell (2005), while countries like Germany and Sweden scored 8.3 and 7.3 respectively. To further examine the impact of institutions on technology adoption, Figure 13 matches country-level data on synthetic indicators on employment protection legislation compiled by the OECD, which measure the costs involved in dismissing workers, and rates of technological change in the workplace from the OECD's PIAAC study (OECD, 2013a). As shown, technology adoption is substantially lower in countries with more strict employment protection, lending further support to the idea that some institutions may hinder technological progress.

32. A compelling piece of evidence on the impact of US institutions and management practices on the implementation of ICT is provided by Bloom et al. (2012), showing that US multinational establishments located in Europe obtained higher productivity gains from ICT than domestic firms and that takeovers by US multinationals (but not takeovers by non-US multinationals) led to a more productive use of ICT.

Figure 13. **EPL and technology adoption in selected OECD countries, 2013**




*Notes*: This figure reports the percentage of workers in the OECD's PIAAC study that reported that the introduction of new processes or technologies in the previous three years that had affected their work environment based on data provided in OECD (2013a) and an employment protection legislation (EPL) index calculated as the unweighted average of "Protection of permanent workers against (individual) dismissal", "Specific requirements for collective dismissal", and "Regulation on temporary forms of employment" each measured on a 0-6 scale that is increasing with the level of protection (see http://www.oecd.org/els/emp/oecdindicatorsofemploymentprotection.htm). Countries included are: Austria, Belgium, Czech Republic, Denmark, Estonia, Finland, France, Germany, Greece, Hungary, Ireland, Italy, Korea, Luxembourg, Netherlands, Norway, Poland, Portugal, Slovak Republic, Slovenia, Spain, Sweden, Turkey, and the United Kingdom. The EPL index is based on 2013 data, except for Slovenia and the UNITED KINGDOM for which data refer to 2014. Also shown is a fitted OLS regression.

## Labour Market Policies for Inclusive Growth

Institutions that promote technological progress need to be accompanied by labour market policies that allow workers to retain their jobs as their task composition changes, or shift into new jobs, as old ones are made obsolete. In other words, in countries experiencing more rapid technological change workers will increasingly have to acquire new skills and reallocate to new types of tasks, occupations, and industries. Active labour market policies (ALMPs) – such as job placement services, special labour market programmes, and wage subsidies – have a potentially important role to play in easing such transitions. Across OECD countries there are substantial differences in both the extent and orientation of ALMPs as they are often deeply embedded in a country's labour market institutions. Thus, while cross-country evidence and the detailed reviews by the OECD of country-level activation strategies suggest that ALMPs contributes to lowering unemployment, the appropriate policy mix differs between countries (Martin, 2015).[33] Because workers are likely to see

33. See, for example, Murtin & Robin (2013), De Serres & Murtin (2013), and OECD (2009). Card et al. (2010) perform a meta-analysis of 199 program estimates drawn from 97 studies conducted between 1995-

further shortened job tenures and an increasing need to reskill, a key area for ALMPs should be to provide flexible training opportunities that are made available to workers throughout work life. Apprenticeships, on-the-job training programs, and online learning tools are particularly suitable to allow workers to acquire specific skillsets that plug emerging skills gaps in the labour market, which tend to yield considerable positive employment effects over the medium term (Card et al., 2010). Taking a more long-term perspective on human capital formation, several OECD countries have also taken steps to integrate the use of digital tools from an early age to promote skills development. In the United Kingdom, for example, children are as of last year learning algorithms and programming from an early age. Although the effects of such policies cannot reliably be evaluated until the exposed individuals enter the labour market, they constitute a sensible complement to short-term policy interventions.

In addition to equipping workers with relevant skills, ALMPs are often focused on incentive reinforcement, raising the take-home pay for workers. For example, evidence suggests that higher labour taxation has a negative effect on employment and growth, although effects are less negative in OECD countries with more competitive labour markets (Daveri and Tabellini, 2000). Similarly, between 1983 and 2003, higher tax wedges were associated with worse employment prospects and higher aggregate unemployment for the average OECD member: a 10 percentage point reduction in the tax wedge contributed to a reduction in equilibrium unemployment by some 2.8 percentage points (Bassanini and Duval, 2006). Labour tax wedges, composed of social security contributions and personal income taxes, are indeed substantial in many OECD countries: in countries such as Belgium and France, for example, the tax wedge amounts to as much as 50 percent for low-wage workers, according to OECD data. The lowering of tax wedges in other words constitutes an important policy lever to increase the net take-home pay for workers, which would increase people's willingness to work while reducing labour costs for employers. In particular, lowering tax wedges has the advantage of increasing the take-home pay for workers at a time of stagnant median wages, without increasing incentives for companies to replace workers with automation technology. The lowering of tax wedges could also be made in a manner that targets disadvantaged groups that may be most adversely affected by technological advances. Yet, while reducing tax wedges provides a way of increasing take-home pay (if gross labour costs remain unchanged) or employment (if gross labour costs decline), taxes wedges have recently increased in 23 OECD member states, while falling in only 9 (OECD, 2015b).[34]

Furthermore, while growing wage dispersion in part can be explained by skill-biased technological change, reductions in top income tax rates, can explain a substantial fraction of the surge in top incomes (Alvaredo et al., 2013). Although raising marginal tax rates for top earners may create disincentives for entrepreneurial pursuits, there are ways of increasing average tax rates for top-income earners without affecting their marginal rates, including the removal of tax credits and deductions that mainly benefit top-income earners, the harmonisation of the taxation of labour and capital, and the shifting of taxation towards immovable property (IMF, 2013). Moreover, as capital-biased technological change is shifting incomes towards capital owners, there is an ongoing debate about the feasibility of also shifting the tax burden from labour to capital. Alvaredo et al. (2013), for example, conclude that since private wealth and inheritance has increased in importance over recent decades, capital income and inheritance taxation will become central tools for policy makers to curb inequality. Indeed, some OECD members have put forward legislative proposals along these lines: in

2007, showing that public sector employment programs have the least favourable impacts and Kluve (2006) similarly conclude that it is the program type that matters—while public sector employment program have detrimental effects, wage subsidies are effective in increasing employment prospects.

34. Similarly, over the past four years, the tax burden has increased in 23 OECD countries and fallen in ten (OECD, 2015b).

the United Kingdom, for example, a mansion tax to be levied on homes worth more than Pounds 2 million has been proposed and the European Commission has proposed a financial transaction tax to be levied on transactions in bonds, derivatives, and shares between financial institutions that reside in the EU area. In addition, to avoid the problems of international "tax shopping", Piketty (2014) has recently argued in favour of a *global* wealth tax, which would amount to one percent on wealth of between Euros 1 to 5 million, with rates increasing at higher levels of wealth.

While a wealth of evidence shows that technological progress has been the key driver of economic growth across countries, rapid technological change in general, and the expanding scope of automation in particular, may put pressure on public finances in many OECD countries, if such progress comes with substantial disemployment among certain skill groups, and the costs of retraining workers add to the already surging costs of education. More radical policy proposals aimed at reducing administrative costs and public transfers should therefore carefully be examined. A basic income guarantee, for example, which involves citizens receiving an unconditional income transfer that replaces other forms of public transfers without any means testing or work requirement is currently being evaluated in some OECD-member states: Finland is preparing a large-scale experiment to evaluate the effects of introducing a basic income guarantee and the Dutch city of Utrecht is initiating a similar experiment. While labour market outcomes of these policy experiments need to be carefully evaluated in terms of their potential adverse effects on incentives to work, there is a good case putting basic income at the centre of discussion.

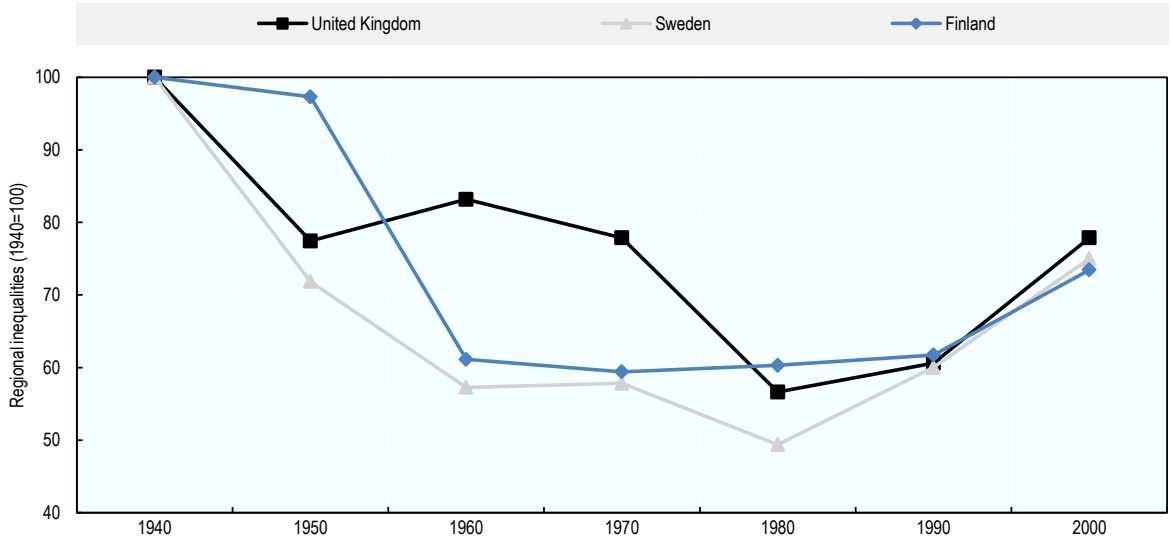
**Human Capital and Regional Development**

While much research has focused on the polarisation of national labour markets, a substantial share of income disparities within countries are associated with prosperity being unevenly distributed across cities and regions. For example, in the United States, the San Francisco metropolitan area has an average per capita income of some Dollars 38 000, while in Laredo, Texas, average incomes are below Dollars 11 000. Within the European Union, regional inequalities are even more striking: in Severozapaden (Bulgaria) GDP per capita is some Euros 6 500, while in Düsseldorf (Germany) incomes average Euros 33 000. Regional inequalities are substantial even within individual European countries such as Spain: in Extremadura, GDP per capita in 2013 was Euros 16 900, compared to Euros 31 600 in Madrid. [35]

Such staggering income disparities exist despite evidence suggesting that poorer regions within a country tend to grow faster than relatively wealthy ones. Estimates by Barro and Sala-i-Martin (1991) suggest that the speed of convergence in the United States was around 2 percent annually between 1880 and 1988. Furthermore, examining 73 regions in seven European countries – including Germany, the United Kingdom, Italy, France, the Netherlands, Belgium and Denmark – over the period 1950 to 1985, they find a similar trend towards convergence. Yet over recent decades, the pace of convergence has seemingly come to halt: the convergence rate between 1990 and 2010 in the United States was less than half the historical norm (Ganong and Shoag, 2012). In most European countries, regional inequalities have increased since the early 1980s, after declining throughout most of the post-War period (see Figure 14).

35. All GDP data cited in the text correspond to PPP-adjusted values, obtained from Eurostat.

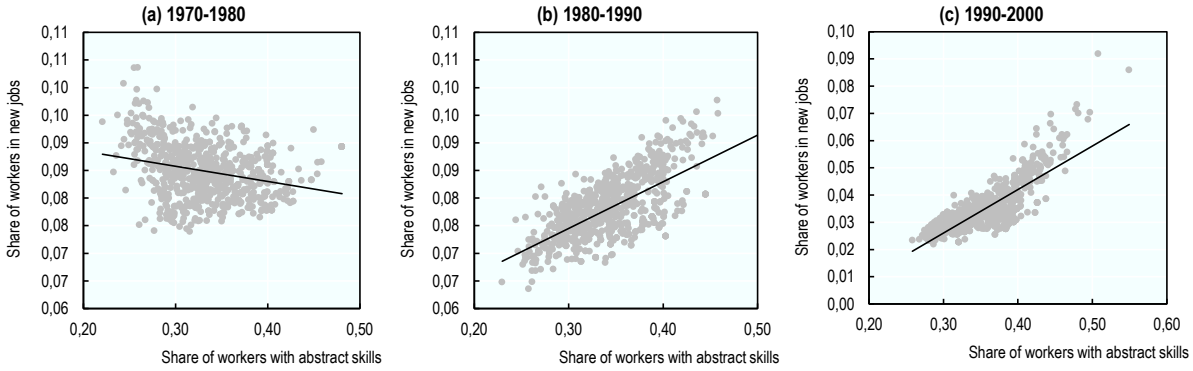
Figure 14. **Regional inequalities have increased since the 1980s**




*Notes*: This figure presents regional inequality measures for Finland, Sweden and the United Kingdom, calculated as the unweighted coefficient of variation for regional per capita GDP in constant prices across NUTS-2 regions indexed to 1940=100. Calculations are based on data for Sweden in Henning et al. (2011), for Finland from Enflo (2014), and the United Kingdom based on estimates provided in Geary and Stark (2015). Note that the United Kingdom data refers to the years 1941, 1951, 1971, 1981, 1991, and 2001, with missing data for 1961, which is linearly interpolated in the figure.

The recent slowdown in income convergence can be explained by the recent divergence of human capital levels across cities and regions and the changing skill requirements of new technology (Berry and Glaeser, 2005; Ganong and Shoag, 2012). In particular, Moretti (2012) has persuasively argued that America's Great Divergence has its origins in the 1980s, when human capital started to dictate the fortunes of US cities. A useful framework for understanding this divergence is provided by Berry and Glaeser (2005), suggesting that it stems from the tendency of skilled entrepreneurs to innovate in ways that create employment opportunities for more skilled workers. An empirical counterpart to this prediction is provided by Berger and Frey (2016b), showing that this tendency is intimately associated with the Computer Revolution of the 1980s, as new computer-related jobs overwhelmingly concentrated to initially skilled cities. Throughout the 1970s, when technological change mainly created routine jobs, human capital abundant cities had a comparative disadvantage in new job creation, as these jobs mainly emerged in routine task – intensive industries – jobs that have since been automated away. By contrast, since the Computer Revolution of the 1980s, cities specialised in cognitive work gained a comparative advantage in new job creation that has persisted since, mirroring trends in population and wage growth across cities over the same period (Figure 15).

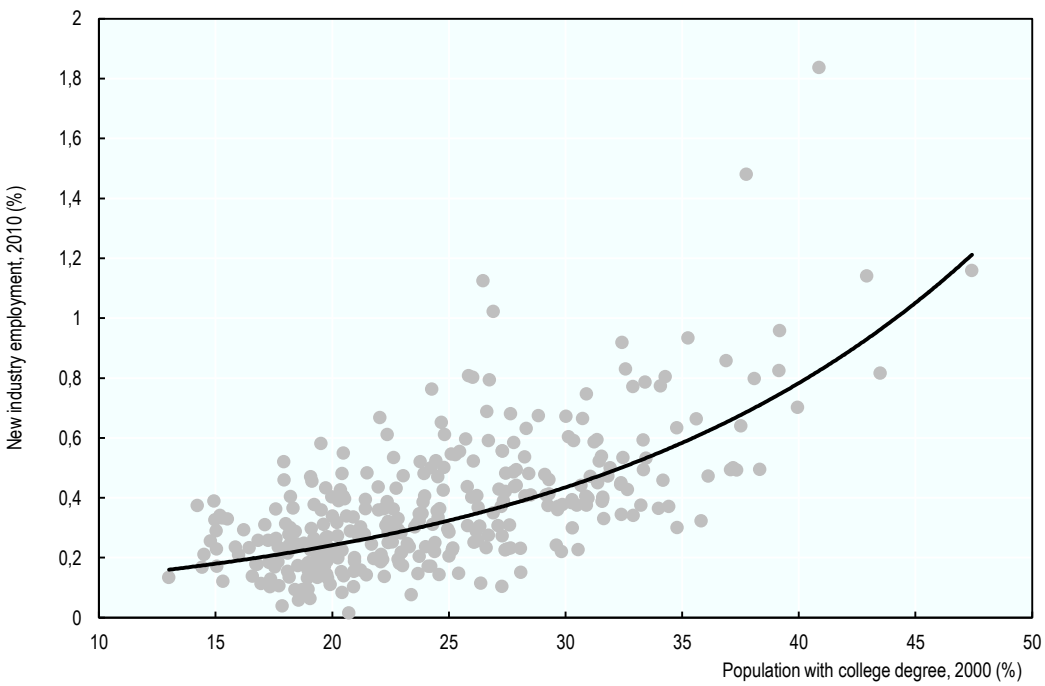
Figure 15. **The Computer Revolution and the reversal in new job creation**




*Notes*: These figures show the share of workers that by the end of each period were employed in jobs that appeared for the first time during each respective period against the share of workers with abstract skills for 321 US cities. Also shown are fitted regression lines. See Berger and Frey (2016b) for information on the underlying data.

This trend has persisted through the 2000s. New industries that emerged throughout the 2000s, are substantially more skill-intensive than other industries, and workers in industries that experienced rapid technological change earn more than twice the US median wage in 2010 (Berger and Frey 2016a). Crucially, these new industries have mainly appeared in urban locations: cities experienced more than 40 percent higher growth in new industry employment between 2000 and 2010 relative to rural areas. In particular, cities that were already dense in college-educated workers experienced substantially more additions of new industries (see Figure 16). In other words, initially skilled cities have created even more jobs for skilled workers.

Figure 16. **New industry creation and skills**




*Notes*: This figure shows the percentage of workers in 2010 that were employed in technology-related industries that were created between 2000 and 2010 against the percentage of the population with a college degree in 2000, for 321 US cities. Also shown is a fitted regression line. See Berger and Frey (2016a) for the underlying data.

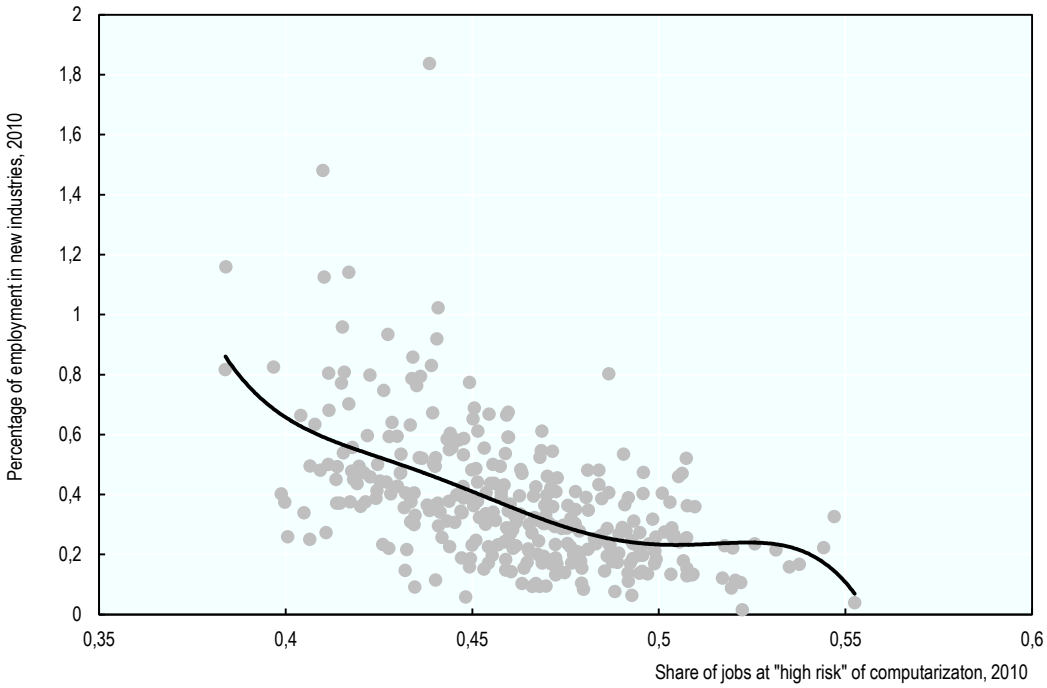
The tendency of new jobs to cluster in skilled cities is not just a US phenomenon. In the United Kingdom, the city of London has served as an incubator for the computer revolution. Examining new job titles that emerged after 1990, Frey (2015) found that 5.5 percent of the United Kingdom workforce had shifted into these new types of jobs by 2004.[36] But by 2014 the proportion of workers in these new types of jobs had increased only modestly to around 6 percent. In Central London, by contrast, the share of total employment in new jobs was 8.6 percent in 2004, growing to 9.8 percent in 2014. Nevertheless, United Kingdom regions experienced some convergence over the investigated period, as regions such as Yorkshire, Tyne and Wear, Wales and Northern Ireland, with low initial employment shares in new jobs experienced higher growth rates.

This convergence in the creation of new jobs however stems from the fact that the rate of regional diffusion was higher than the pace of new job creation, following a sharp decline in the creation of new jobs throughout the 2000s. A useful model for understanding this process is provided by Duranton and Puga (2001), suggesting that young firms, which need to experiment to grow, benefit from knowledge spillovers facilitated by the density of cities, especially throughout the innovation phase. Once a firm has identified its ideal prototype, and production processes become more standardised, the company tends to relocate to cities where production costs are lower. In other words, skilled places constitute "nursery cities" for new job creation. As these jobs become more standardised they tend to diffuse also to less skilled places, leading to convergence across locations unless skilled cities produce new jobs at a faster pace than old ones diffuse.

While data on the emergence of new jobs across countries is sparse, a recent study by Goos et al. (2015), examining the share of high-tech employment across the EU27 regions shows that convergence is taking place, but at a glacial pace. At the current pace of convergence the lagging regions of Europe will need at least 60 years just to close half their gap with Europe's leading high-tech clusters. Stockholm remains the leading urban area in terms of tech-employment, with 18 percent of its 1.1 million labour force employed in high-tech jobs. While the workforce of the Centro region of Portugal is of similar size, only 4 percent of jobs are high-tech. According to the authors estimates it will take the Centro region at least until 2070 to reach 11 percent of high-tech employment and close half of the gap to Stockholm.

36. Eight of the ten occupational categories in which these new job titles arose were related to computers, so this can largely be linked to the computer revolution.

Figure 17. **Cities at risk**




*Notes*: This figure shows the percentage of workers in 2010 that were employed in technology-related industries that were created between 2000 and 2010 from Berger and Frey (2016a) and the share of jobs at "high risk" of computerisation in 2010 from Frey and Osborne (2013) across 321 US cities. Also shown is a fitted regression line.

Meanwhile, throughout the 2000s, new jobs in the United States have emerged in places that are relatively safe from automation, while cities with a larger share of their workforce exposed to the expanding scope of automation have failed to create new jobs (see Figure 17). Hence, new jobs are being created in different locations from the ones where old jobs are likely to disappear, potentially exacerbating the ongoing divergence between cities and regions. Looking forward, this trend may require workers to relocate from contracting to expanding cities.[37] Supporting such relocation is particularly important since the arrival of new technology jobs creates additional demand for local services. Across locations in Europe, estimates suggest that local high-tech job multiplier is around five (Goos et al., 2015). That is, every high-tech job in a region creates five other jobs outside high-tech in that region. Thus, while technology does perhaps not create as many jobs directly as in the past, its indirect impact on service employment is substantial. Nevertheless, because new technology jobs overwhelmingly cluster in highly skilled cities, low skilled workers will inevitably have to follow, making economic activity increasingly concentrated.

37. It might indeed be argued that because ICT industries seemingly have accounted for almost no net job creation in recent years, there should not be any large impact on the spatial organisation of national labour markets, requiring many low-skilled workers to migrate to the high-skill cities where ICT is concentrated. Even combined with a local jobs multiplier of 5, the small job creation numbers for the ICT sector are unlikely to imply large local employment gains and large migrations of workers. Nevertheless, technology-using professional services, equally benefiting from knowledge spillovers, have accounted for a more substantial share of recent job growth across OECD economies. Furthermore, even if only few new jobs are created in skilled cities, workers in declining regions will be better off moving to expanding cities. For example, Hsieh & Moretti (2015) show that lowering regulatory constraints on housing in skilled cities would significantly expand the workforce.

Does this imply that governments should create subsidies to spread economic activity between locations? Not necessarily. As noted by Gottlieb and Glaeser (2009), if agglomeration economies exist, which plenty of empirical evidence suggests, then moving people or firms from one area to another simply means that one area gets more productive and the other less. On the contrary, since people and firms cluster to benefit from knowledge spillovers, policies aiming to spread economic activity across locations may reduce overall productivity. Instead workers are likely to benefit from the option of relocating to skilled cities: while they do not receive the urban wage premium immediately, they benefit in terms of faster wage growth, implying more rapid accumulation of human capital (Glaeser and Mare, 2001).

Policies to increase geographical mobility, especially among the unskilled, should target the cost of housing and the cost of moving. As skilled cities are becoming more attractive, rising house prices makes them less affordable. This has implications particularly for the unskilled, who often lack the financial means to relocate to places where new jobs are available – something that is evident from studies of both the United States and France (Anderson et al., 2014; Gobillon et al., 2007). Housing constraints can also provide constraints on growth.[38] The reason why unskilled workers are less mobile across locations relative to the skilled does however not just relate to the supply of housing. Because relocation is like an investment, where a worker spends money upfront for the opportunity to get a job, and many unskilled workers arguably do not have the financial means for the investment, there is a case for subsidizing their relocation.[39]

While making skilled cities more affordable places to live, and increasing geographical mobility, policies should simultaneously focus on increasing the innovation potential of lagging regions. Because human capital spillovers exist, subsidizing education should increase social welfare, without pushing talent in one direction or another. Research shows that the presence of a college or university increases the supply of college educated workers not just by educating more of them, but also by attracting more of them from the outside (Moretti, 2005). Furthermore, the presence of a university generates important knowledge spillovers that benefit local innovation sectors.

The importance of human capital for industrial renewal is highlighted by the case of Boston (Glaeser, 2005). Since the formation of Boston in 1630, the city has reinvented itself from being a seaport, to a factory town, to becoming a centre for information technology. This transition required the formation of new types of human capital throughout the process. Similarly, today's lagging regions will need to adapt their skills and structures to the expanding technology frontier. For example, work by Goos et al. (2015) suggests that the slow convergence in high-tech employment among the EU 27 regions relates to obstacles that hinder faster accumulation of human capital as well as physical capital in lagging regions. Filippetti and Peyrache (2015) further argue that although investments in fixed capital such as infrastructure and transportation networks, may provide a positive shock to productivity in lagging

38. Hsieh & Moretti (2015), for example, have calculated that growing wage dispersion across locations reduced aggregate US GDP by 13.5 percent between 1964 and 2009, resulting from constraints to housing supply in skilled cities like New York, San Francisco and San Jose. They further show that the potential gains in output and welfare from spatial reallocation of labour are substantial: lowering regulatory constraints on housing in these cities to the level of the median city would expand their work force and increase US GDP by 9.5 percent. In other words, expanding the supply of housing in skilled cities would not only help unskilled workers, but the economy as a whole.

39. A bold proposal to increase their mobility has been put forward by Moretti (2012), arguing that relocation vouchers would incentivise workers to move to places where new jobs are being created. For example, if a less-skilled worker moves from Andalucía (where unemployment is 35 percent) to get a job in Barcelona, then that worker will pay higher taxes in the future and require fewer transfer payments from the government. Because such mobility from high unemployment to low unemployment areas generates positive externalities, an argument in favour of relocation vouchers is easy to make.

regions, capital accumulation is subject to diminishing returns. Thus, simultaneous investments in technology and human capital is becoming increasingly important for lagging regions to move towards the frontier and for countries to achieve sustained convergence.

**Conclusions**

The diffusion of digital technologies has had pervasive effects on labour markets across the OECD. In particular, a growing body of work shows that technological change since the computer revolution has (i) increased the demand for cognitive skills; (ii) reduced the demand for workers performing routine tasks; and (iii) contributed to the declining labour share of national income. In addition, the arrival of new technologies has significantly altered the composition of the workforce across the dimensions of industries, occupations, and tasks. The decline of manufacturing employment and the reallocation of workers to services can in part be explained by automation of manufacturing jobs, and the creation of entirely new service industries such as video and audio streaming as well as web design. Furthermore, while digital technologies have made many occupations redundant – including the ones of bookkeepers, data entry keyers, and typists – it has created occupations such as those of software engineers and database administrators. Digital technologies have also significantly altered the task composition of jobs: while the traditional tasks of a bank teller have largely been displaced by ATMs, the job of a bank teller today contains many new client relationship management tasks.

While it is evident that labour markets across the OECD countries are undergoing rapid transformation, driven in part by the arrival of digital technologies, implications for the future of jobs is far from certain. On the one hand, accumulating anecdotal evidence shows that the potential scope of automation has expanded beyond routine work, making technological change potentially increasingly labour-saving. On the other hand, there is evidence suggesting that digital technologies have not created many new jobs to replace old ones: an upper bound estimate is that around 0.5 percent of the US workforce is employed in industries that emerged throughout the 2000s, associated with the arrival of new technologies. Nevertheless, at first approximation, there is nothing to suggest that the digital revolution so far has reduced overall demand for jobs. Instead most job growth has taken place in technologically stagnant sectors of the economy, including health care, government and personal services. More speculatively, however, we argue that while these sectors have been technologically stagnant in the past, the expanding scope of automation is likely to make many of them technologically progressive in the future, with implications for skill requirements. While recent studies suggest a reversal in the demand for college educated workers, we argue that this is most likely a result of faltering job creation in new technology industries. As digital technologies are making inroads on most jobs also outside the technology sector, this is likely to significantly alter the demand for skills.

Finally, we emphasise the role for education, labour market, and tax policy in exploiting the opportunities and responding to the challenges that are associated with the increased penetration of digital technology in the workplace. In particular, investing in skill upgrading is a key policy lever not only to revive faltering productivity growth, but also to mitigate further unwanted increases in inequality while ensuring that ample economic opportunity is available to workers in the twenty-first century. As economic activity is becoming more concentrated to skilled cities – reflected in a breakdown of regional convergence since the 1980s – there is a growing risk that disadvantaged areas are left behind. To improve the economic potential of lagging regions, policies should aim to increase the mobility of unskilled workers, while at the same time targeting inflated housing prices in rapidly expanding areas. Policy makers should promote investments in skill development, to improve the innovative capacity of lagging regions and facilitate new job creation. Finally, investments in education complemented with investments in fixed capital – such as digital and physical infrastructure – are becoming increasingly important to allow disadvantaged regions to achieve sustained convergence.

**References**

Acemoglu, D. (1998), “Why do new technologies complement skills? Directed technical change and wage inequality”, Quarterly journal of economics, pp. 1055-1089.

Acemoglu, D. and D. Autor (2011), “Skills, tasks and technologies: Implications for employment and earnings”, Handbook of labour economics, No°4, pp. 1043-1171.

Acemoglu, D., D. Dorn, G.H. Hanson and B. Price (2014), “Return of the Solow paradox? IT, productivity, and employment in US manufacturing”. *National Bureau of Economic Research*, No. w19837.

Akerman, A., I. Gaarder and M. Mogstad, (2015), “The Skill Complementarity of Broadband Internet. The Quarterly Journal of Economics”, Vol. 130, No. 4, pp. 1781-1824.

Alvaredo, F., A. B. Atkinson, T. Piketty and E. Saez, (2013), “The Top 1 Percent in International and Historical Perspective. *The Journal of Economic Perspectives*, Vol. 27, No. 3, pp. 3-20.

Andrews, D., C. Criscuolo and P. Gal (2015), “Frontier firms, technology diffusion and public policy: micro evidence from OECD countries”, Manuscript, OECD.

Atasoy, H. (2013), “The Effects of Broadband Internet Expansion on Labour Market Outcomes”, *Industrial and Labour Relations Review*, No. 66, pp. 315–345.

Autor, D. H. (2015), “Why are there still so many jobs? The history and future of workplace automation”, *The Journal of Economic Perspectives*, Vol. 29, No. 3, pp. 3-30.

Autor, D. H. and D. Dorn (2013), “The growth of low-skill service jobs and the polarisation of the US labour market”, *American Economic Review*, Vol. 103, No. 5, pp. 1553–97.

Autor, D., F. Levy and R.J. Murnane (2003), “The skill content of recent technological change: An empirical exploration”, *The Quarterly Journal of Economics*, Vol. 118, No. 4, pp. 1279-1333.

Autor, D.H. (2014), "“Skills, education, and the rise of earnings inequality among the “other 99 percent”". *Science*, Vol. 344, No. 6186 pp. 843-851, 23 May.

Azmat, G., A. Manning and J. Van Reenen (2012), “Privatisation and the Decline of the Labour’s Share: International Evidence from Network Industries”, *Economica*, No. 79, pp. 470–492.

Barro, R. J., X. Sala-i-Martin, O.J. Blanchard and R.E. Hall (1991), “Convergence across states and regions”, *Brookings papers on economic activity*, pp. 107-182.

Bartel, A., C. Ichniowski and K. Shaw (2007), “How Does Information Technology Really Affect Productivity? Plant-Level Comparisons of Product Innovation, Process Improvement and Worker Skills”, *Quarterly Journal of Economics*, No. 122, pp. 1721–1758.

Bartelsman, E., P. Gautier and J. De Wind (2010), “Employment Protection, Technology Choice, and Worker Allocation”, Institute for the Study of Labour - IZA Discussion Papers No. 4895

Barth, E., A. Bryson, J.C. Davis and R. Freeman (2014), "It's where you work: Increases in earnings dispersion across establishments and individuals in the US", National Bureau of Economic Research, No. w20447.

Bassanini, A. and T. Manfredi (2012), "Capital's Grabbing Hand? A Cross-country/Cross-industry Analysis of the Decline of the Labour Share", OECD Social, Employment and Migration Working Paper, OECD Publishing, Paris.

Bassanini, A. and R. Duval, (2006). "Employment Patterns in OECD Countries: Reassessing the Role of Policies and Institutions", OECD Economics Department Working Paper No. 486.

Basu, S. and J. Fernald (2007), "Information and Communications Technology as a General-Purpose Technology: Evidence from US Industry Data", *German Economic Review*, Vol. 8, No. 2, pp. 146-173.

Baumol, W. J. (1967), "Macroeconomics of unbalanced growth: the anatomy of urban crisis", The American Economic Review, 415-426.

Baumol, W., S.B. Blackman and E.N. Wolff (1989), "Productivity, growth and American leadership: the long view", *The MIT Press*.

Beaudry, P., M. Doms and E. Lewis (2010). "Should the personal computer be considered a technological revolution? evidence from us metropolitan areas", *Journal of Political Economy*, Vol. 118, No. 5, pp. 988-1036.

Beaudry, P., D. A. Green, and B. M. Sand (2013), "The great reversal in the demand for skill and cognitive tasks", National Bureau of Economic Research, No. w18901.

Bentolila, S. and G. Saint-Paul (2003), "Explaining Movements in the Labour Share", *B.E. Journal of Macroeconomics*, No. 3.

Berger, T. and C.B. Frey (2016a), "Industrial Renewal in the 21st Century: Evidence from US Cities", Regional Studies, forthcoming.

Berger, T. and C.B. Frey (2016b), "Did the Computer Revolution Shift the Fortunes of US Cities? Technology Shocks and the Geography of New Jobs", Regional Science and Urban Economics, forthcoming.

Berman, E., J. Bound and Z. Griliches. (1994), "Changes in the Demand for Skilled Labour within US Manufacturing: Evidence from the Annual Survey of Manufactures", *Quarterly Journal of Economics*, Vol. 109, pp 367-397.

Berry, C. R. and E.L. Glaeser (2005), "The divergence of human capital levels across cities", *Papers in regional science*, Vol. 84, No. 3, pp. 407–444.

Bertschek, I., D. Cerquerab and G. Kleinc (2013), "More Bits—More Bucks? Measuring the Impact of Broadband Internet on Firm Performance", *Information Economics and Policy*, Vol. 25, No. 3, pp. 190–203.

Blanchard, O. (1997), "The Medium Run", *Brookings Papers on Economic Activity*, No. 2, pp. 89-158.

Blanchard, O. and F. Giavazzi. (2003), "Macroeconomic Effects of Regulation And Deregulation In Goods and Labour Markets", *Quarterly Journal of Economics*, No. 118, pp. 879-907.

Blinder, Alan S. (2006), "Offshoring: the next industrial revolution?", *Foreign Affairs*, No. 85.2, pp. 113.

Blinder, Alan S. (2009), "How Many US Jobs Might Be Offshorable?", *World Economics*, Vol. 10, No. 2, pp. 41-78.

Bloom, N., F. Guvenen, D.J. Price and J. Song (2015), "Firming up inequality. Centre for Economic Performance", LSE, No. dp1354.

Bloom, N., R. Sadun and J. Van Reenen (2012), "Americans Do IT Better: US Multinationals and the Productivity Miracle", *American Economic Review*, Vol. 102, No. 1, pp 167-201.

Bolt, J. and J. L. van Zanden (2014), "The Maddison Project: collaborative research on historical national accounts", *The Economic History Review*, Vol. 67, No. 3, pp. 627651.

Brynjolfsson, E. and L.M. Hitt (2000), "Beyond computation: Information technology, organisational transformation and business performance", *The Journal of Economic Perspectives*, pp. 23-48.

Brynjolfsson, E. and A. McAfee (2014), "The second machine age: Work, progress, and prosperity in a time of brilliant technologies", WW Norton and Company.

Brynjolfsson, E., A. McAfee and F. Zhu (2009), "Leaders and Laggards: IT and the Growth of Performance Differences Between Firms. Mimeo.

Brynjolfsson, E., and L. M. Hitt, (2003), "Computing Productivity: Firm-Level Evidence", *Review of Economics and Statistics*, No. 85, pp. 793–808.

Card, D., J. Kluve and A. Weber (2010), "Active Labour Market Policy Evaluations: A Meta-Analysis", *The Economic Journal*, Vol. 120, No. 548, pp. F452-F477.

Caroli, E. and J. Van Reenen (2001), "Skill-biased organisational change? Evidence from a panel of British and French establishments", *Quarterly journal of economics*, pp. 1449-1492.

Caselli, F. and W.J. Coleman (2001), "Cross-Country Technology Diffusion: The Case of Computers", *The American Economic Review*, Vol. 91, No. 2, pp. 328-335.

Chetty, R., N. Hendren, P. Kline, and E. Saez, (2014), "Where is the land of Opportunity? The Geography of Intergenerational Mobility in the United States", *The Quarterly Journal of Economics*, Vol. 129, No. 4, pp. 1553-1623.

Colombo, M. G., A. Croce and L. Grilli (2013), "ICT Services and Small Businesses Productivity Gains: An Analysis of the Adoption of Broadband Internet Technology", *Information Economics and Policy*, Vol. 25, No. 3, pp. 171-89.

Comin, D. and B. Hobijn (2009), "Lobbies and technology diffusion, The Review of Economics and Statistics", Vol. 91, No. 2, pp. 229-244.

Conway, P., D. De Rosa, G. Nicoletti and F. Steiner (2006), "Regulation, competition and productivity convergence", OECD Economics Working Paper 509.

Corrado, C. A and C. R. Hulten (2010), "How Do You Measure a "Technological Revolution?", *American Economic Review*, Vol. 100, No. 2, pp. 99-104.

Crafts, N. (2004), "Steam as a general purpose technology: A growth accounting perspective", *The Economic Journal*, Vol. 114, No. 495, pp. 338-351.

Crafts, N., and G.Toniolo, (2010), "Aggregate growth, 1950-2005", *The Cambridge Economic History of Modern Europe*, No. 2, pp. 296-332.

Crivellaro, E. (2014). "College wage premium over time: trends in Europe in the last 15 years", University Ca'Foscari of Venice, Dept. of Economics Research Paper Series, No 3.

Daveri, F., G. Tabellini (2000), "Unemployment, Growth and Taxation in Industrial Countries", *Economic Policy*, Vol. 15, No. 30, pp. 47-104.

David, P. A. (1990), "The dynamo and the computer: an historical perspective on the modern productivity paradox", *The American Economic Review*, pp. 355-361.

De Serres, A., and F. Murtin (2013), "Do policies that Reduce Unemployment Raise its Volatility? ", OECD Economics Department Working Papers, No. 1020, OECD Publishing.

Deloitte (2015a), "From brawn to brains: The impact of technology on jobs in the United Kingdom", Deloitte, London.

Deloitte (2015b), "Man and Machine: Robots on the rise? The impact of automation on the Swiss job market", Deloitte.

Dickens, R., S. Machin, and A. Manning (1999), "The Effects of Minimum Wages on Employment: Theory and Evidence from Britain", *Journal of Labour Economics*, Vol. 17, No. 1, pp. 1-22.

DiNardo, J.E., and J-S. Pischke, (1997), "The returns to computer use revisited: Have pencils changed the wage structure too? ", *Quarterly Journal of Economics*, No. 112, pp. 291-303.

Duranton, G., and D. Puga (2001), "Nursery cities: Urban diversity, process innovation, and the life cycle of products", *American Economic Review*, pp. 1454-1477.

Enflo, K. (2014), "Finland's regional GDPs 1880-2010: estimates, sources and interpretations", Department of Economic History, Lund University, No. 135.

ETLA (2014), "Computerisation Threatens One-third of Finnish Employment".

Filippetti, A. and A. Peyrache, (2015), "Labour Productivity and Technology Gap in European Regions: A Conditional Frontier Approach", Regional Studies, Vol. 49, No. 4, pp. 532-554.

Freeman, R. B. (1995), "Are your wages set in Beijing?", *The Journal of Economic Perspectives*, pp. 15-32.

Frey, C. B., (2015), "New job creation in the UK: which regions will benefit most from the digital revolution?", PwC, http://www.pwc.co.uk/assets/pdf/ukeo-regional-march-2015.pdf.

Frey, C.B. and M.A. Osborne (2014), "UK Jobs at Risk?, In: Agiletown: the relentless march of technology and London's response, Deloitte, http://www2.deloitte.com/uk/en/pages/growth/articles/agiletown-the-relentless-march-of-technology-and-londons-response.html.

Frey, C. B., and M.A. Osborne (2013), "The Future of Employment: How Susceptible are Jobs to Computerisation?", *Oxford Martin School Working Paper*.

Ganong, P. N., and D.W. Shoag, (2012), "Why Has Regional Convergence in the US Stopped?", Mimeo;

Geary, F. and T. Stark, (2015), "What happened to regional inequality in Britain in the twentieth century?", *The Economic History Review*.

Glaeser, E. L. (2005), "Reinventing Boston: 1630–2003", *Journal of Economic Geography*, Vol; 5, No. 2, pp. 119-153.

Glaeser, E. D. and D. Maré (2001), "Cities and Skills", *Journal of Labour Economics*, Vol. 19, No. 2, pp. 316-42.

Gobillon, L., H. Selod and Y. Zenou, (2007), "The mechanisms of spatial mismatch", *Urban studies*, Vol. 44, No. 12, pp. 2401-2427.

Goldin, C. and L.F. Katz (1998), "The origins of technology-skill complementarity", *The Quarterly Journal of Economics*, Vol. 113, No. 3, pp. 693-732.

Goldin, C. and L. F. Katz (2008), "The Race between Education and Technology", *Cambridge: Harvard University Press*.

Goos, M. and A.Manning (2007), "Lousy and lovely jobs: The rising polarisation of work in Britain", *The Review of Economics and Statistics*, Vol. 89, No. 1, pp. 118–133.

Goos, M., J. Konings and M. Vandeweyer, (2015), "Employment Growth in Europe: The Roles of Innovation, Local Job Multipliers and Institutions", Local Job Multipliers and Institutions, October.

Goos, M., A. Manning, and A. Salomons. (2014), "Explaining Job Polarisation: Routine-Biased Technological Change and Offshoring", *American Economic Review*, Vol. 104, No. 8, pp. 2509-2526.

Goos, M., A. Manning, and A. Salomons (2009), "Job Polarisation in Europe", *The American Economic Review*, Vol. 99, No. 2, pp. 58-63.

Gordon, R. J. (2012), "Is US economic growth over? Faltering innovation confronts the six headwinds", National Bureau of Economic Research, No. w18315.

Gottlieb, J. D., and E. L. Glaeser (2009), "The Wealth of Cities: Agglomeration Economies and Spatial Equilibrium in the United States. Journal of Economic Literature, 47(4), 983-1028.

Graetz, G., and G. Michaels (2015), "Robots at work", CEP Discussion Paper, No 1335.

Green, F. (2012), "Employee involvement, technology and evolution in job skills: A task-based analysis", *Industrial and Labour Relations Review*, Vol. 65, No. 1, pp. 36-67.

Grimes, A., C. Ren, and P. Stevens (2012), "The Need for Speed: Impacts of Internet Connectivity on Firm Productivity", *Journal of Productivity Analysis*, Vol. 37, No. 2, pp. 187-201.

Haller, S., and S. Lyons (2015), "Broadband Adoption and Firm Productivity: Evidence from Irish Manufacturing Firms", Telecommunications Policy, No. 39, pp. 1-13.

Haltiwanger, J., , I. Hathaway and J. Miranda (2014), "Declining business dynamism in the US high-technology sector", Available at SSRN 2397310.

Hanushek, E. A., G. Schwerdt, S. Wiederhold and L. Woessmann (2015), "Returns to Skills around the World: Evidence from PIAAC", *European Economic Review*, No. 73, pp. 103-130.

Henning, M., K. Enflo and F. N. Andersson (2011), "Trends and cycles in regional economic growth: How spatial differences shaped the Swedish growth experience from 1860–2009", *Explorations in Economic History*, Vol. 48, No. 4, pp. 538-555.

Hsieh, C. T., and E. Moretti (2015), "Why Do Cities Matter? Local Growth and Aggregate Growth", National Bureau of Economic Research, No. w21154.

IMF (2013), "Taxing Times", *Fiscal Monitor*, October

Ingram, B. F. and G. R. Neumann (2006), "Returns to skill", *Labour Economics*, Vol. 13, No. 1, pp. 35-59.

Kaldor, N. (1957), "A model of economic growth", *The economic journal*, pp. 591-624.

Karabarbounis, L., and B. Neiman (2014), "The Global Decline of the Labour Share", The Quarterly Journal of Economics, Oxford University Press, Vol. 129, No. 1, pp. 61-103.

Katz, L. F., and K. M. Murphy (1992), "Changes in Relative Wages, 1963-1987: Supply and Demand Factors", *The Quarterly Journal of Economics*, Vol. 107, No. 1, pp. 35-78.

Kluve, J. (2006), "The effectiveness of European active labour market policy", IZA Discussion Paper No. 2018.

Koeniger, W., M. Leonardi, and L. Nunziata (2007), "Labour Market Institutions and Wage Inequality", *Industrial and Labour Relations Review*, Vol. 60, No. 3, pp. 340-356.

Krueger, A.B. (1993), "How computers have changed the wage structure: evidence from microdata, 1984–1989", *The Quarterly Journal of Economics*, Vol. 108, No. 1, pp. 33-60.

Krugman, P. R. (1994), "Rethinking international trade", MIT press.

Krugman, Paul R. (2008), "Trade and Wages, Reconsidered", *Brookings Papers on Economic Activity*, No. 2, pp. 103–137.

Lawrence, R. Z., M. J. Slaughter, , R. E. Hall, , S. J. Davis, and R. H. Topel, (1993), "International trade and American wages in the 1980s: giant sucking sound or small hiccup? ", *Brookings papers on economic activity*, Microeconomics, pp. 161-226.

Lee, J. (2015), "Measuring Agglomeration: Products, People, and Ideas in US Manufacturing", pp. 1880-1990, Mimeo

Lin, J. (2011), "Technological adaptation, cities, and new work", *Review of Economics and Statistics*, Vol. 93, No. 2, pp. 554-574.

Timmer, M.P., G. J. de Vries and K. de Vries (2014), "Patterns of Structural Change in Developing Countries", GGDC research memorandum 149 .

Machin, S. (1997), "The decline of labour market institutions and the rise in wage inequality in Britain", *European Economic Review*, Vol. 41, No. 3-5, pp. 647-657.

Machin, S., and J. Van Reenen, (1998), "Technology and Changes in Skill Structure: Evidence from Seven OECD Countries. Quarterly Journal of Economics, 113 (1998), 1215–1244.

Martin, J. P. (2015), Activation and active labour market policies in OECD countries: stylised facts and evidence on their effectiveness. IZA Journal of Labour Policy, 4(1), 1-29.

Mazzolari, F. and G. Ragusa (2012), Spillovers from High-Skill Consumption to Low-Skill Labour Markets. Review of Economics and Statistics, forthcoming.

McKinsey (2015), "Four fundamentals of workplace automation. McKinsey Quarterly, Nov.

MGI (2013), "Disruptive technologies: Advances that will transform life, business, and the global economy, Tech. Rep., McKinsey Global Institute.

Michaels, Guy, A. Natraj, and J. Van Reenen (2014), "Has ICT Polarised Skill Demand? Evidence from Eleven Countries over 25 Years. Review of Economics and Statistics, Vol. 96, No. 1, pp. 60-77.

Moravec, H. (1988), Mind Children, Harvard University Press.

Moretti, E. (2010), Local Multipliers, *American Economic Review*, Vol. 100, No. 2, pp. 373-77.

Moretti, E. (2012), The new geography of jobs, Houghton Mifflin Harcourt.

Nickell, S. (2005), "What Has Happened to Unemployment in the OECD since the 1980s?, Presentation to Work and Pensions Economics Group, HM Treasury.

Nicoletti, G., and S. Scarpetta (2006), "Regulation and economic performance: product market reforms and productivity in the OECD Institutions, Development, and Economic Growth, pp. 81-120.

Nordhaus, W. D. (2007), "Two centuries of productivity growth in computing", *The Journal of Economic History*, Vol. 67, No. 01, pp. 128-159.

OECD (2009), OECD Employment Outlook 2009, OECD Publishing. http://dx.doi.org/10.1787/empl_outlook-2009-en

OECD (2012), OECD Employment Outlook 2012, OECD Publishing, Paris. http://dx.doi.org/10.1787/empl_outlook-2012-en

OECD (2013a), OECD Skills Outlook 2013, First Results from the Survey of Adult Skills, Paris: OECD, 2013. http://dx.doi.org/10.1787/9789264204256-en

OECD (2013b), Skills for the Digital Economy. OECD Skills Strategy Spotlight No. 4. http://skills.oecd.org/developskills/documents/skillsforthedigitaleconomy.html.

OECD (2015a), OECD Digital Economy Outlook 2015, OECD Publishing, Paris. http://dx.doi.org/10.1787/9789264232440-en

OECD (2015b), Taxing Wages 2015, OECD Publishing, Paris. http://dx.doi.org/10.1787/tax_wages-2015-en

O'Mahony, M., and M. P. Timmer (2009), Output, input and productivity measures at the industry level: The EU KLEMS database. The Economic Journal, 119(538), F374-F403.

Piketty, T. (2014), Capital in the 21st Century, Cambridge, Harvard University.

Polanyi, M. (1966), The Tacit Dimension, New York, Doubleday.

Reardon, S.F. (2011), The widening academic achievement gap between the rich and the poor: New evidence and possible explanations, Whither opportunity, pp. 91-116.

Rodrik, D. (2015), Premature Deindustrialisation, National Bureau of Economic Research, No. w20935.

Rowthorn, R., and R. Ramaswamy (1997), Deindustrialisation: Causes and Implications, Staff Studies for the World Economic Outlook, 1997, 61.

Sachs, J.D., and J. K. Lawrence (2012), Smart Machines and Long-Term Misery, NBER Working Paper No. 18629, December.

Smith, A., and J. Anderson, (2014), AI, robotics, and the future of jobs, Pew Research Center.

Spence, M., and S. Hlatshwayo, (2012), The evolving structure of the American economy and the employment challenge. Comparative Economic Studies, Vol. 54, No. 4, pp. 703-738.

Spitz-Oener, A. (2006), Technical change, job tasks, and rising educational demands: looking outside the wage structure. Journal of Labour Economics Vol. 24, No. 2, pp. 235-270.

Spitz-Oener, A. (2008), The returns to pencil use revisited. Industrial and Labour Relations Review Vol. 61, No. 4, pp. 502-517.

SSF (2014), Vartannat job automatiseras on 20 år – utmaningar för Sverige.

Summers, L. (2015), Making Sense of the Productivity Slowdown, Peterson Institute conference.

Syverson, C. (2013). Will History Repeat Itself? Comments on ‘Is the Information Technology Revolution Over?’, International Productivity Monitor, No. 25, pp. 37-40.

Tambe, T. and Hitt, L.M. (2012), Now IT's Personal: Offshoring and the Shifting Skill Composition of the US Information Technology Workforce, Management Science Vol. 58, No. 4, pp. 678-695.

The Guardian (2015), Robots are leaving the factory floor and heading for your desk – and your job. The Guardian, February 9th.

Tinbergen, J. (1974), Substitution of Graduate by Other Labour, Kyklos No. 27, pp. 217-226.

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

van Ark, B. (2014), Productivity and Digitalisation in Europe: Paving the Road to Faster Growth, Lisbon Council Policy Brief Vol. 8, No. 1.

Van Welsum, D., and X. Reif (2005), Potential offshoring: Evidence from selected OECD countries. In Brookings Trade Forum, pp. 165-194, Brookings Institution Press.

Wood, A. (1995a), How trade hurt unskilled workers, The Journal of Economic Perspectives, pp. 57-80.

Wood, A. (1995b), North-South trade, employment and inequality: changing fortunes in a skill-driven world, OUP Catalogue.

World Bank (2016), Digital Dividends, World Development Report.