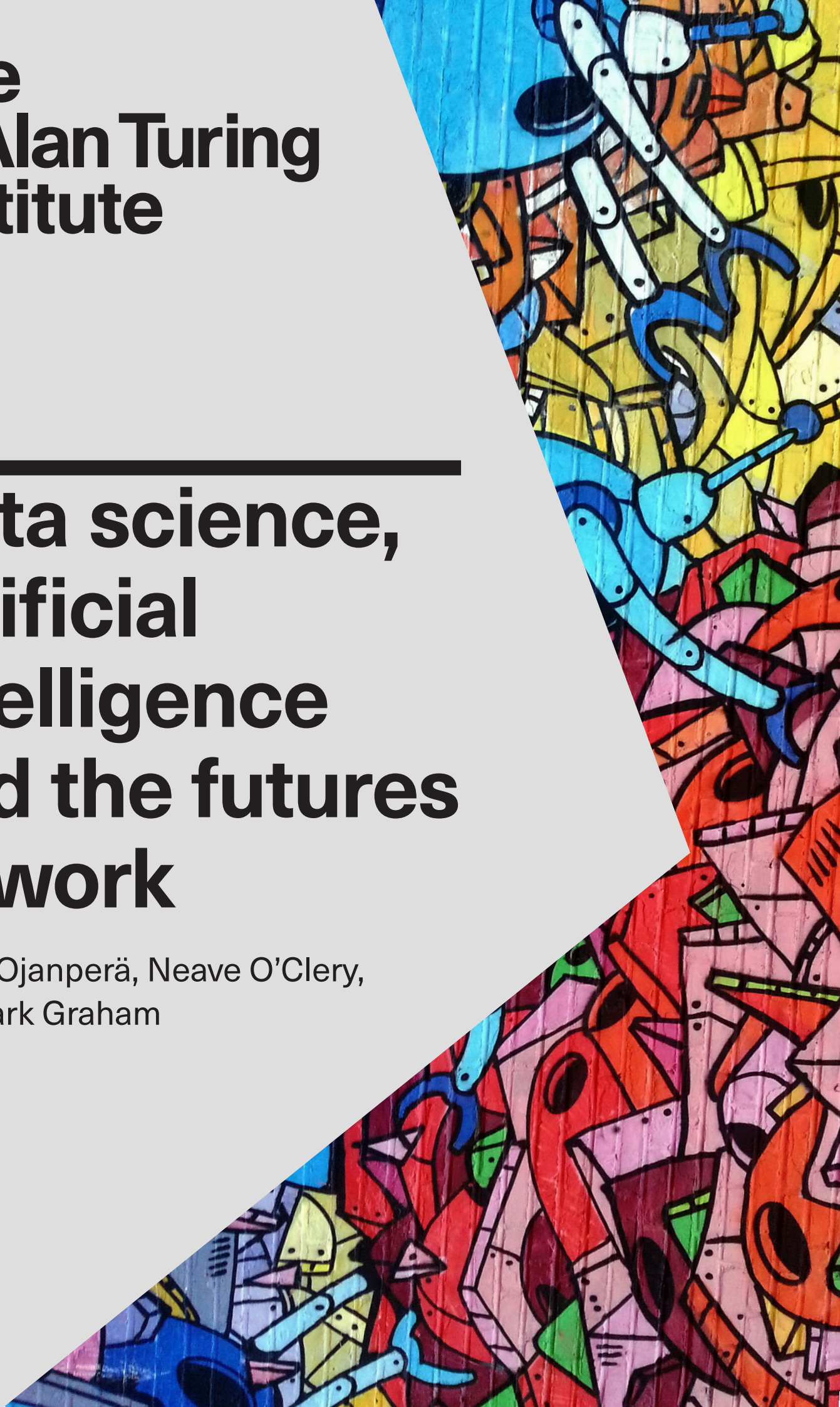
The Alan Turing Institute

Data science, artificial intelligence and the futures of work

Sanna Ojanperä, Neave O'Clery, and Mark Graham



The Alan Turing Institute

https://doi.org/10.5281/zenodo.1475162

This work was supported by The Alan Turing Institute under the EPSRC grant EP/N510129/1

Data science, artificial intelligence and the futures of work

October 2018

Sanna Ojanperä [1,*], Neave O'Clery[2], and Mark Graham[1]

[1] Oxford Internet Institute, University of Oxford and The Alan Turing Institute
[2] Mathematical Institute, University of Oxford and The Alan Turing Institute
* Corresponding author: Sanna Ojanperä, sanna.ojanpera@oii.ox.ac.uk

Overview

In this document, we offer a review of recent literature on the future of work. This review was commissioned by The Alan Turing Institute for the purpose of informing the Institute's research strategy aiming to further data science and artificial intelligence research to address real-world problems. Using a critical review method, the report synthesises key findings about the future of work focusing on three main areas: broad research findings, emerging research directions and innovative data science research directions. The first part of the review summarises and discusses changes in the nature and creation of jobs, assignments and tasks; changing organisation of work and production; varying impacts of the changing nature of work on society; and the governance of these changes through politics, policy and institutions. The second section addresses potential drivers of the changing nature of work; disparate impacts of technology on different tasks; challenges for young people to boost employability; impacts of the changing nature of work on the disenfranchised; and proposals for policies and governance models to manage the transitions related to the future of work. The third section discusses research approaches and findings around the susceptibility of tasks and assignments to computerisation; industrial diversification and data-driven policy tools; and development of online labour markets.

Many commentators point to inevitable technological changes in the future of work. However, the overview that emerges from this review of the material suggests that multiple possible futures exist that depend on complex dynamics between context, choices and adaptability to new circumstances shaping the opportunities for individuals, firms, civil society organisations, governments and international organisations. Recent research on the topic has identified challenges, including rising inequality between and within countries, loss of jobs, hardship faced by younger generations and the disenfranchised and algorithmic control in the workplace. However, the changing nature and organisation of jobs and the adoption of new technologies throughout the economy, also gives rise to new opportunities, such as new jobs in both technology-driven and traditional industries. Widening market access, better-suited models to govern and regulate the changing nature and organisation of work and improved workplace technology are other areas where changes may lead to positive outcomes. While these changes affect economies and societies differently around the world, the challenges and opportunities give rise to research opportunities and open up avenues for collaboration and learning.

The changing nature and organisation of work and its diverse impacts on societies will need to be understood through not just best practice applied to new topics, but also emerging research approaches and themes rooted in data science and artificial intelligence, such as machine learning, robotics and network science. As the future of work quickly becomes the present, there is an urgent need for scholarship that attempts to understand how to make our new world of work sustainable, equitable and just.

Table of contents

List of tables and figures

1. Introduction

This document presents a review of existing literature on the future of work. This review has been commissioned by The Alan Turing Institute to inform the Turing research strategy aiming to further data science and artificial intelligence (AI) research to address real-world problems. Using a critical review method, this report synthesises key findings on the future of work drawing from high-quality academic and policy literature across a range of disciplines and sectoral backgrounds and focusing on the state of knowledge, key applications of data science, and avenues for future research. This review adopts an international scope with special reference to the UK and discusses central research findings within three main sections: broad research findings, emerging research directions, and innovative data science research directions.

2. The scope of the review: The changing future of work in the global context

This report reviews perspectives and evidence from around the world while maintaining special reference to the context in the United Kingdom. The discussion spans different levels of analysis, including individuals, firms, civil society organisations, governments and international organisations, as the key research findings concentrate on various levels of analysis which are of interest for the Turing. While many of the research pieces reviewed discuss the future of work in a global context and as part of a global dialogue, the reader should keep in mind that many of the concepts used in discussions about the future of work have context-specific meanings. The full-time working model that is often considered to be 'standard' (and its contrast as a trade-off to the concept of leisure) is an artefact that has existed only for a few decades in a handful of countries mainly located in Europe and North America. For the majority of the rest of the world, work continues to be underpinned by precarious employment in informal settings, characterised by long hours and vulnerable conditions with narrow or lacking social protection. While those who enjoy greater prosperity and a wider variety of capacities may be leading many of the discussions about the future of work, we have made an effort to include also the perspectives and viewpoints of those who have accumulated less.

Following the critical review methodology of Grant and Booth (2009), we synthesise the key findings on the future of work focusing in three main areas: broad research findings, emerging research directions, and innovative data science research directions (see Table 1). Within each area, the review provides a comprehensive overview of the area, brings together the key findings through critically outlining the state of knowledge, identifying gaps in the literature, and pointing out avenues for future research. The rest of the review proceeds to discuss the three areas in turn and concludes with a discussion on the research avenues that we expect to be of interest to future Turing activities.

Table 1. The structure of the review.

Broad research findings	Emerging research directions	Data science research directions
- Changes in the nature and creation of jobs, assignments and tasks - Changing organisation of work and production - Varying impacts of the changing nature and organisation of work on society - Governance of these changes through politics, policy and institutions	- Potential drivers of the changing nature of work - Disparate impacts of technology on different tasks - Challenges for young people to boost employability - Impacts of the changing nature of work on the disenfranchised - Proposals for policies and governance models to manage the transitions related to future of work	- Susceptibility of tasks and assignments to computerisation - Industrial diversification and data-driven policy tools - Development of online labour markets and the gig economy

3. Broad research findings

While the future of work is a framework that includes many agents and processes which are in flux, there are certain broad findings that the academic, business and policy communities seem to agree on. In this section, we summarise and discuss the main findings related to the broad concept of the future of work, including changes in the nature and creation of jobs, assignments and tasks; changing organisation of work and production; varying impacts of the changing nature of work on society; and governance of these changes through politics, policy and institutions.

3.1. Changes in the nature and creation of jobs, assignments and tasks

While the hallmark phenomenon of the 'changing nature of jobs' (i.e. the shift of jobs to the service, communication, transportation and creative sectors from manufacturing) is evident in many advanced economies, this is not the case everywhere. In China, manufacturing employment continues to drive the economy (Hou, Gelb, & Calabrese, 2017) while in many low and middle-income economies, the share of manufacturing employment and the share of informal employment has remained stable (World Bank, 2019). The structure of the economic base is relatively constant in many parts of the world, but other aspects of work are changing, and this process is more pronounced in the advanced economies (World Bank, 2019). Alternative work arrangements are on the rise and in the United States the percentage of employment in temporary help agency workers, on-call workers, contract workers, and independent contractors or freelancers rose from 10.1% in February 2005 to 15.8% in late 2015 (Katz & Krueger, 2016).

The nature of employment is in flux all around the world, as more diverse forms of work emerge and as human capital has become an increasingly important requirement for many jobs. Labour markets progressively reward general cognitive skills such as problem solving and critical thinking as well as one's adaptability and readiness for change and socioemotional skills related to one's ability to manage and identify emotions that help in effective communication and team work (Ajwad et al., 2014; Bodewig, Badiani-Magnusson, McDonald, Newhouse, & Rutkowski, 2014; Sudakov et al., 2016; Valerio, Sanchez Puerta, Tognatta, & Monroy-Taborda, 2016). The emergence of new technologies affects skills requirements through job creation in technology-driven industries and integration in more traditional sectors such as agriculture, requiring adoption, adaptation, operating and managing these technologies (Sudakov et al., 2016). While skills-intensive jobs are on the rise, employment shifts away from middle-skilled occupations involving routine tasks, which can be more readily substituted by technology, in particular automation (Sachs & Kotlikoff, 2012).

The World Bank (2019) estimates that since 2000, the percentage of jobs in occupations requiring non-routine cognitive and socio-emotional skills has increased from 19 to 23%in developing countries and from 33 to 41% in advanced economies, while the decline in the share of employment in occupations involving routine skills has fallen from 50 to 44% in developing countries and from 42 to 32% in advanced economies. In advanced economies as well as in Indonesia, Mexico and Brazil, labour markets are polarizing (also termed as hollowing-out), as in addition to growth in high-skilled jobs, low-skilled jobs requiring physical dexterity and interpersonal communication are also on the increase at the expense of the middle-skilled jobs (D. Autor, 2014; D. H. Autor & Dorn, 2013; Maloney & Molina, 2016; Michaels, Ashwini, & Van Reenen, 2014; Acemoglu & Autor, 2011; World Bank, 2019).

The geography of jobs has also changed in particular through the emergence of online platforms and trade extending market access. Online labour platforms such as UpWork, Freelancer and Fiverr enable working remotely for clients around the world, while country based platforms such as CrowdWorks in Japan and Giraffe in South Africa as well as sector-specific platforms such as Gigster for high-end

software development and UpCounsel for legal services cater for more specific markets (Sundararajan, 2017). Digital marketplaces facilitate the sale of physical goods to a wider variety of clients and can support businesses in locations where the local demand is weak. For instance, Taobao.com, one of the largest online marketplaces in China owned by Alibaba, has enabled various communities of rurally-based workers to trade goods through online shops (Guihang, Qian, & Guangfan, 2014). One of the most profound ways in which platforms are changing the geography of jobs is by creating what might be thought of as a 'planetary labour market' in which workers, for the first time, have to grapple with instant competition for jobs with workers from around the world (Graham & Anwar, 2018), and this creates a huge oversupply of labour power on many platforms (Graham, Hjorth, & Lehdonvirta, 2017). Beyond freelance work and trade through platforms, the incidence of remote working through digital technologies enables working on different schedules or from different locations even in more traditional workplaces. 37% of workers in the United States and 17% in Europe telework at least occasionally (World Bank, 2019).

3.2. Changing organisation of work and production

Beyond the changes in the types and composition of jobs, the organisation or work and production is transforming in a number of ways. While wage labour has existed throughout history, the concept of a standard employment relationship—characterised by full-time employment in a firm, a permanent contract, payment of adequate remuneration to support a family and provision of benefits—was only formed over the past couple of decades and hasn't been adopted as the prevalent model beyond a small part of the world including Europe, North America, Japan, and Australia (International Labour Organization, 2017). Today, this archetypal 'standard model' has given way to diverse forms of paid labour, such as temp work, part-time jobs, subcontracting, the use of independent contractors, dependent or independent self-employment and casual labour (Bernhardt, 2014).

The emergence of new jobs in digitally-enabled contexts such as online labour platforms and platforms commercializing personal assets such as transportation platforms tends to further erode the traditional employment relationship and fragmentise the role of the employer (International Labour Organization, 2017). Where digital platforms allow for work that would previously have been carried out by a full-time employer to be distributed to on-demand workers and where certain tasks can be automated, the resulting economy may increasingly depend on short-term freelance employment relationships (Sundararajan, 2017). An estimated 4% of workers in the United States, France, Germany, Spain, Sweden and the United Kingdom have earned income through such platforms (Lepanjuuri, Wishart, & Cornick, 2018; Sundararajan, 2017).

The past decades have witnessed international production, trade and investments become increasingly organised in global value chains where the various stages of the production process are located in different countries (Marcolin & Squicciariani, 2017). These processes have distributed activities such as design, production, marketing and distribution across the world, and in particular supported the outsourcing of jobs to low- and middle-income countries. However, robotisation and automation disrupts global value chains by so called 'reverse offshoring', where outsourced jobs are replaced by these technologies (World Bank, 2019). The importance of this phenomenon is contested and Backer et al (2016) argue that instead of leading to new jobs, the reshoring activities are likely to result in capital investment in terms of robotics and possibly a small number of high-skilled additional jobs in the 'home' countries (back-shoring) or in the neighbouring countries (near-shoring). Wiesmann et al (2017) find that most of the academic papers published on the topic had a focus on the United States or Europe suggesting the geographic patterns of these activities being located in the advanced economies.

A recent review by the British Academy and the Royal Society finds that nearly two thirds of the labour related to automatable activities resides in China, India, Japan and the United States (2018). The other countries with large amounts of workers likely affected include France, Germany, Italy, Spain and the United Kingdom, for which the estimated figure is 10-30% of jobs being highly automatable (British Academy & The Royal Society, 2018).

3.3. Varying impacts of the changing nature of work on society

The changes discussed above affect societies in complex ways. While the discourse around the future of work often predicts the job-destroying effect of automation, many voices agree that a bigger concern is the rising inequality within countries and between them (British Academy & The Royal Society, 2018; Srnicek, 2016). Where automation and robotisation lead to productivity gains, the profits are reaped by owners of capital, and if they are not be reinvested to production purposes, they will concentrate wealth in the hands of few social actors (British Academy & The Royal Society, 2018; International Labour Office, 2017). On the other hand, these productivity gains may allow workers to focus on more creative tasks and new jobs may be created in the process where demand will respond swiftly to changing prices and incomes (World Bank, 2019). The changing nature of jobs seems to feature increasing returns to high-skilled jobs across the world and to low-skilled jobs requiring dexterity (such as gardening, plumbing, care services for the young and elderly) in advanced economies while the middle-skilled jobs tend to face decreasing returns (British Academy & The Royal Society, 2018). These changes could lead to falling wages for both middle-skilled workers because of automation and for low-skilled workers because of increased competition for the jobs requiring dexterity and interpersonal communication (World Bank, 2019). Moreover, these developments may lead to higher wage inequality where high-skilled workers enjoy increasing wages and the middle and lower parts of the skills distribution encounter decreasing wages (D. Autor, 2014).

Many of the reviewed reports agree that, in previous industrial revolutions, initial disruptions following technological innovation have been short-lived, and have ultimately led to improvements in job quality (British Academy & The Royal Society, 2018; International Labour Organization, 2017). Over the past century, technologies have reduced the need for labour in many jobs and sectors, but also created jobs in many fields producing more jobs than have been replaced (World Bank, 2019). While some scholars warn that the pace of change is much faster this time around leaving limited space for labour markets to adjust pre-emptively or react to changes that are taking place, the published work on the topic tends to agree that the productivity-enhancing and market proximity expanding effects of technology will be large and the most immediate negative impact will be the rise in inequality. The tendency towards deformalisation and fractionalisation of the employment relationship in particular transforms the nature of work in advanced economies closer to the realities of labour markets in developing economies. In other words, this means that this facet of labour markets in developed and developing countries is converging—a surprising trend, given that over the past century economic development has mainly comprised of efforts in formalisation of the economy and in advancing the manufacturing sector (World Bank, 2019).

3.4. Governance of these changes through politics, policy and institutions

The changes discussed above are likely to exacerbate current inequalities at least in the short run (International Labour Organization, 2017). As the structures, norms, and institutions that have formed a stable basis for governing the organisation of work and production are changing, governments are faced with the question of whether new or different kinds of structures and governance models are needed to address the emerging challenges. In the discourse between international organisations and various governments the following themes have emerged as some of the key governance challenges related to the future of work: the management of employment relationships particularly in terms of

social protection and in terms of reducing the impact of marketisation, adjusting taxation systems to finance these changes and regulation of global value chains.

Labour market institutions and social protection systems are fundamental pillars of societies even in low-income countries. Whereas the majority of workers in developing countries lack formal protection, labour markets are fragmenting and becoming more fluid in advanced economies. Many labour market institutions and social protection systems are formulated around the 'standard' employment relationship, but the realities of today's labour markets are disjointed with the expectations underpinning this model. The need to develop new ways to manage this 'new informality' may not only offer better suited policies for advanced economies, but also allow developing countries with less mature systems to scrutinise policy options that may be a better fit for the 'old informality' (The Roosevelt Institute, 2015).

Many of the reports reviewed highlight that the governance of these transitions can be carried out through politics, policy and institutions. While policy solutions will likely look different across the various contexts of governance, social dialogue and trade unions in particular are highlighted as structures that may offer relevant mechanisms to manage labour relations, but require adaptation to better respond to the new fragmented labour markets. Other proposed governance models that address the changing labour markets from a more radical standpoint include various mechanisms of redistribution of productivity gains, including citizen's income, rights-based regimes and a new social contract. Various voices also underline that while emerging governance gaps should be addressed carefully, this exercise should not cloud the need for continuing the challenging work of devising tax, regulatory, trade and other policy changes, which will likely affect labour markets (Mishel, Schmitt, & Shierholz, 2013; Stiglitz, 2013).

4. Emerging research directions

The second section of this review addresses emerging research directions that point out to key questions in the broad findings and offer avenues for future research. The section discusses the research findings around the following topics: potential drivers of the changing nature of work; disparate impacts of technology on different tasks; addressing the particular challenges for young people to boost employability; impacts of the changing nature of work on the disenfranchised; and proposals for policies and governance models to manage the transitions related to future of work.

4.1. Potential drivers of the changing nature of work

The changing nature of work, including sectoral, industrial, and occupational composition, diversity of working arrangements, skill requirements and geography are multifaceted phenomena that manifest differently in contexts around the world. While it is not straightforward to evaluate the causal relationships driving these changes across the multiplicity of different contexts they take place in, an emerging body of research around this theme has suggested some potential drivers that are at play, namely, technology, globalisation and trade, demographic changes, human capital development, governance and climate change.

The role of technology in driving changes in the nature of jobs is highlighted in many of the published materials on the topic. Some authors argue that while innovation in particular in AI, automated vehicles, robotics, 3D printing and nano-technology is now in its infancy, it has the potential to transform the economy and produce unemployment especially when the cost of technology will fall (Brynjolfsson 2016; McAfee 2017). The authors explain that unrelenting advances in computing power and data storage will lead to exponential growth in technological capacity as predicted by Moore's law, and

result in wide-scale disruption in the labour markets (Brynjolfsson, 2016). Others point out that the impact of technology on the nature of jobs is overblown, while demographic changes, declining educational attainment and rising debt ratio are more significant drivers (Gordon, 2014).

Globalisation, or the development of an integrated global economy, is also argued to form an important driver of the changes in the nature of work. While technology plays a role, some argue that it is rather the free movement of capital and labour across global markets that is driving the changes in work. (International Labour Organization, 2017; UNCTAD, 2017). With the widening global markets, companies tend to adopt an international strategy fragmenting production chains and targeting certain areas for specialised skills. The fact that offshoring and reshoring are hard to predict as specific locations may mature quickly adds to the disruption to local labour markets.

Other arguments suggest that focusing on technology as a driver diverts attention away from the work on devising policies and institutions, which are key drivers affecting the nature of work and in particular leading to many of the inequalities observable in the labour markets today (The Roosevelt Institute, 2015). Some accounts posit that demographic changes play a large role, as in certain developing countries in Africa and South Asia in particular, large cohorts of youth join the local labour market where jobs are scarce, while large formal firms, which in many countries employ a large share of the labour market, are few and face restricted growth due to barriers in trade and regulation (Djankov, La Porta, Lopez-de-Silanes, & Shleifer, 2002; Goldberg, Khandelwal, Pavcnik, & Topalova, 2008; World Bank, 2019). Finally, events related to climate change and responses to it in particular within the domain of green growth (Fankhauser, Sehlleier, & Stern, 2008; Olsen, 2009; OECD, 2012) and rapid urbanisation (Coulibaly et al., 2008) affect the location as well as composition of jobs.

4.2. Disparate impacts of technology on different tasks

While machines have been replacing workers for centuries, and robots for decades, the recent frontier of computer-assisted technology and AI in particular will have disparate impacts on different tasks. Much of the research in this area agrees that routine tasks, which are relatively easily codifiable, face the potential of automation. Computers are able to process any task for which logical rules or statistical models have a solution (Levy & Murnane, 2013). However, non-routine and more complex tasks that require either cognitive skills or emotional qualities are likely to not be affected by automation (Levy & Murnane, 2013). Machines have surpassed humans in tasks that are routine and well-defined, resulting in loss of jobs related to production and clerical tasks (Dorn, 2015; Dorn & Autor, 2013). The number of robots is increasing rapidly with the majority serving electrical, electronics, automotive, metal and machinery industries (World Bank, 2019). Others argue further stating that if there are no significant engineering bottlenecks due to advances in data mining, machine vision, computational statistics, mobile robotics or AI, any non-routine task could be automated (Frey & Osborne, 2017).

Beyond the impacts of automation on employment numbers, as the trend of job fragmentation facilitates the breakdown of complex tasks into simpler ones, tasks within jobs can be automated. Repetitive, routine and physical tasks within jobs are affected both in ‘blue collar’ as well as in ‘white collar’ jobs. Beyond automation, the introduction of novel technologies such as 3D printing may lead to the disappearance of certain industries, where entire production processes might be relocated and altered in order to bring production into closer proximity to clients or resources (International Labour Organization, 2017).

However, predicting how technology will affect jobs is tricky and the estimates vary widely. The World Bank reviewed the range in job automation estimates for different countries and found large discrepancies in the results: for the United States, the estimates range between 7 and 47% of jobs being affected, for Japan between 6 and 55%, and for Bolivia between 2 and 41% (World Bank, 2019).

However, the authors of this study mention that these estimates must be considered carefully due to a range of difficulties related to such measurements including: strong reliance on expert opinion, reliance on occupational categories from the United States in contexts outside of that country, not properly accounting for industrial structures or competitive advantages of different countries, not accounting for the absorption of displaced workers in other sectors, and not incorporating technology absorption rates (World Bank, 2019).

Automation can also create new jobs. For instance, some of the developments in the field of bioinformatics have been driven because the use of computers requires specific skills in designing and managing data and analytical software ("Science must examine the future of work," 2017). Other examples include growth in the ICT and technology sectors of various countries, as well as growth through digital marketplaces fostering trade, and digitally-enabled work through online labour platforms and the gig economy. Technology is less likely to affect jobs in the non-tradeable goods and services sectors, where social interaction, creative thinking, and innovation are key characteristics of the jobs. Tourism, education, and health care are sectors in which the integration of technology will likely improve productivity, but won't lead to a reduction of jobs, as demand is rising as a result of growing populations and prosperity (World Bank, 2019).

4.3. Challenges for young people to boost employability

While the changing nature and organisation of work stands to impact societies and economies around the world, there is one group of individuals for whom these changes are particularly salient—the 'millennials'. Born between 1980 and early 2000s, millennials have surpassed the previous generations—Generation X and Baby Boomers—as the largest generation in history, and now comprise a third of the world's population (Riad, 2017). Many entered the labour force when the Global Financial Crisis of 2008 had worsened economic circumstances to the deepest historic low since the Great Depression. The present working trajectories and future economic decisions of this generation will be greatly affected by the changing nature and organisation of work. While millennials are better educated than the previous generations, they face less certainty and lower incomes in the labour market (Burke, 2017). Even though the levels of technological penetration and participation vary around the world, the millennial generation is largely digitally native and uses digital devices and software in the workplace as well as in their daily life.

These skills come in necessary as the speed of technological change is likely to be much faster for this generation than it has been for previous generations (Riad, 2017). This means that many millennials and those born after them (forming 'Generation Z') will need to be prepared to learn new skills at various points over their careers (Riad, 2017). Further, these generations, more than their predecessors, need to learn adaptability—the ability to respond to unexpected circumstances and un-learn and re-learn at a fast pace (World Bank, 2019). While socio-emotional skills and combinations of different skill types are growing more important due to their resistance for technological substitution and transferability across different job contexts, job-specific skills face more uncertainty. As the speed of technological development increases, many of the generation entering primary school now will work in careers that do not yet exist and thus investment in skills that are transferable across jobs seems like a more secure strategy.

The World Bank identifies three domains as the cornerstones of development for these relevant skills: early childhood, tertiary education and adult learning outside jobs. In order for millennials and Generation X to obtain education that prepares them for the changing labour market, targeted investments in these three areas are needed. This is a challenge given that the youth around the world are far from being a homogenous group, as large differences in gender, income, access to education,

existing skill level and geography affect who is better positioned to embrace the opportunities in the changing labour market (International Labour Organization, 2017).

4.4. Impacts of the changing nature of work on the disenfranchised

While changes in the nature of work are driven by a host of factors such as policy-making, demographic change, climate change and rapid urbanization, technology and globalization seem to be the two megatrends having diverse impacts on the nature, composition and location of jobs (OECD, 2017). As these changes appear to increase inequality both within and between countries, an emergent research and policy direction is investigating this further and asks to what extent and to whom these changes enable taking advantage of new opportunities or form a new expression of extractive economic practices.

On one hand, the availability of digitally-mediated work through online labour platforms or through making income from utilising assets via sharing and gig economy platforms such as apartments via AirBnB or cars through Uber, Lyft, and GrabTaxi extend economic opportunities that may have previously been available in certain locations. Digital commercial platforms extend market access, and can support workers in locations that don't have large enough local demand to consume the goods. Global value chains outsource jobs to new locations, while reshoring removes these jobs where technology can replace some or all of the related tasks. While the expansion of job opportunities and access to markets offer new opportunities, it is not clear how the quality of these opportunities trades off with the uncertainty that is characteristic of many of them (Sundararajan, 2017).

The lack of regulation in many of the newly emerged contexts of non-standard work leaves open many questions about worker rights and benefits. Investigating digitally mediated work, Moore (2018) points out to the emerging forms of harassment and violence that workers face. She mentions that algorithmic management of reputation systems on digital platforms fuels stresses and creates risks in workload management, while digital surveillance of working practices may additionally introduce discrimination (Moore, 2018). Investigating work quality in the gig economy, Wood et al (2018) find that while algorithmic management techniques tend to offer workers high levels of flexibility, autonomy, task variety and complexity, these mechanisms can also result in low pay, social isolation, working unsocial and irregular hours, overwork, sleep deprivation and exhaustion.

Where lack of regulation combines with a diminishing role of the employer, the impacts on vulnerable or disadvantaged communities on the basis of gender, race, age, income, and education are not well understood (The Roosevelt Institute, 2015). In particular, as middle-skill jobs are facing reducing demand and the labour market rewards high-skilled jobs and certain low-skilled jobs, those regions with a short supply of workers with STEM skills will face challenges (International Labour Organization, 2017). Non-tradeable goods and services sector might offer opportunities for transition to those workers with middle- and low-skills, but cost of retraining, low pay and limited upward mobility remain challenges (World Bank, 2019). Additionally, AI-driven changes in the labour market might produce varying geographical effects across countries and regions where the people likely to have positive or negative returns to the introduction of AI are clustered and similar dynamics may be at play for other technologies (British Academy & The Royal Society, 2018).

While the changing nature of work impacts many developing countries, the larger concern for their labour markets is the high level of informality and limited productivity (Chen, 2012). Workers in the informal economy often face low wages and lack social protection (Perry et al., 2007). As labour markets in advanced economies are growing increasingly informal, the need of governments and policy-makers to devise policies to govern redistribution of profits, regulate the non-standard

employment relationships and global value chains, and organise social protection might create new models to govern increasingly informal labour markets.

Developing new governance models may benefit developing countries, as these models may be better suited for economies with large pools of informal labour (International Labour Organization, 2017). In the United Kingdom, creating a cashless government-accredited platform for transactions related to hiring self-employed labour is suggested as a solution that could reap an estimated several billions in additional revenues from work that would otherwise be carried out informally (Taylor, Marsh, Nicol, & Broadbent, 2017).

4.5. Proposals for policies and governance models to manage the transitions related to future of work

The future of work will be characterised by increasing inequality both between and within countries. A key question that multilateral organisations and governments with varying types of regimes and institutions face is whether the existing institutions and processes to govern work are still fit for purpose and how they should evolve to address the challenges in current conditions. While policy solutions will likely look different across the various contexts of governance, in order to ensure decent living conditions for everybody, redistribution of wealth is suggested to offer a key mechanism that governments and multilateral organisations can utilise in order to ensure equality of opportunity and avoid social conflict (International Labour Organization, 2017).

A related issue to tackle is the increased individualism of work and a parallel erosion of labour relations, which have further hindered the governance of work using the traditional tools and mechanisms (International Labour Organization, 2017). The majority of social protection systems and labour regulations such as minimum wages and severance pay are built upon the concept of formal wage-labour contracts (World Bank, 2019). However, several tools that better address the current conditions have been proposed and highlight the role that policy-making on governmental and intergovernmental level can have in managing the transitions related to the changing nature and organisation of work and in ensuring that they are consensual. Baker (2014) suggests that political will is what is needed to alter institutional structures in order to broadly share gains from technology. The World Bank urges future policies to be 'rights-based, consensual, and founded on global solidarity and global governance' and states that 'social justice and human welfare should be the guiding principles' (World Bank, 2019).

4.5.a. Social dialogue

In terms of adjusting conceptualisations, as the 'standard' employment relationship is becoming less popular while 'non-standard' forms of work are growing, the concept of work addressed within the setting of social dialogue and policy-making could be broadened beyond wage labour to include relevant categories of unpaid work, in particular in the care industries (International Labour Organization, 2017). Further, fostering a normative dialogue between the social partners and institutions could guide the development of new governance models and ethical conventions for instance for AI and its applications (International Labour Organization, 2017). International organisations in particular consider social dialogue to offer a suitable framework for designing new models of governance as long as the representativeness of social partners is widened to include transnational companies and informal or unregulated workers (International Labour Organization, 2017). The International Labour Organization (2017) also suggests the introduction of European models of social dialogue into developing countries, while modifying them to fit the national contexts and allow negotiation between different actors as well as addressing particular problems in different sectors.

As an example, following the Rana Plaza building collapse in Bangladesh, the Accord on Fire and Building Safety in Bangladesh was created as a binding agreement between two global trade unions, over 2,000 clothing brands and local trade unions among other actors (International Labour Organization, 2017).

4.5.b. Redistribution policies

Redistribution processes vary largely between countries, as tax and social protection systems have evolved into various shapes, and while they redistribute income rather effectively in the advanced economies, the rate is much lower in developing countries where collection of revenue and spending on social protection are low (World Bank, 2019). However, despite the large informal economy, redistribution policies in Latin America, especially in Brazil have been successful in distributing wealth from capital to labour (International Labour Organization, 2017).

4.5.c. Guaranteed social minimum

An alternative model that would cover all workers, including in the informal economy, would be the introduction of state-funded programs that provide protection to all those who work. While many programs providing an inclusive, guaranteed social minimum have been tested, but rarely widely taken up, there are also new alternatives such as universal basic income or negative income tax. Universal basic income offers the entire population a standard level of income transfer, and claims back parts of it through taxation, mainly from the wealthy. Negative income tax directly provides more benefits to those with no or low incomes and progressively reduces the amount of benefits as income raises. While both of these options would offer a solution addressing the marketisation of labour, they have been questioned in terms of affordability, political feasibility and societal fairness and have not been adopted beyond a few experiments in Finland, the United States, Netherlands, Canada and Kenya (International Labour Organization, 2017; World Bank, 2019). The only universal basic income trials covering an entire population took place in Mongolia from 2010 to 2012 and in Iran in 2011 (Tabatabai, 2012; World Bank, 2019; Yeung & Howes, 2015).

4.5.d. Rights-based regimes and taxation

A rights-based regime offers another alternative governance model, but further work on defining and interpreting the rights would be required. A few advanced economies have developed tools to introduce technologies gradually and accompanied by social partners' negotiations on conditions and rights, such as right to retraining (International Labour Organization, 2017). Another approach would be taxing the adoption of new technologies, in particular of robots (Guerreiro, Rebelo, & Teles, 2017; International Labour Organization, 2017). However, taxing robots introduces concerns about negative incentives for faster automation in order to cover the costs of the robot tax through increasing productivity. Additionally, as differentiating discrete units of labour associated with automation is likely to become more difficult, where AI is bundled together with machinery, taxation might lead to taxing capital investment (International Labour Organization, 2017). More efficient taxation for platform companies and superstar firms could also be developed in order to improve the tax revenues in the various countries that they have presence.

4.5.e. Private governance

Another group of alternative models focuses on private governance. During the carnival in Brazil, a semi-legal approach was applied without formalising work, as temporary workers were offered short-term service contracts, which included basic guarantees through the negotiation of a commercial contract (International Labour Organization, 2017). Terming the practice 'regulatory acupuncture', the

International Labour Organization (2017) suggests that government actors (including judges, labour inspectors, and health and safety inspectors) could facilitate the innovation of such creative solutions without the need to increase bureaucracy. Additionally, profit-sharing and worker-ownership schemes offer alternatives where those with capital aren't pitted against those earning their income from labour. Profit-sharing schemes are popular in South Africa and France, and are especially effective in engaging trade-unions in the dialogues (International Labour Organization, 2017).

4.5.f. Regulating global supply chains and digital platforms

Global supply chains that transcend borders and various regulatory systems present a special case for governance. Realigning control and responsibility could be achieved either through centralizing and realigning responsibility to business enterprises or by decentralizing control to the local level, or as a combination of both approaches. Governments can regulate intermediaries which act as links between multinational firms and local firms, and such approaches are in place in Latin America and Indonesia. The International Labour Organization (2017) recommends that multiple national certifications be replaced with a single institutional certification, one set of rules for certification, and one institution that would be in charge of inspection and certification. Innovative initiatives have also been adopted in relation to global supply chains, as in France large employers are obliged to report on human rights in global value chains (International Labour Organization, 2017). One approach that is currently in its pilot stages is a certification scheme (dubbed the Fairwork Foundation[i]) for platforms that mediate labour. Because digital platforms such as Uber or Upwork do not consider themselves employers, but rather as mediators of supply and demand for services, protections associated with the traditional employment model do not apply to their workers. As such, the Fairwork Foundation aims to emulate some of the successes of organisations like the Fairtrade Foundation and the Living Wage Foundation in order to set minimum standards in the gig economy and certify digital platforms that achieve them (Graham & Woodcock, 2018).

4.5.g. Collective bargaining

While it has enjoyed variable success across different contexts of governance, collective bargaining has traditionally been one of the most effective ways that workers have been able to improve their livelihoods. As such, trade unions will ultimately need to adapt fast to quickly changing technological realities such as the platform economy. In order to include more of the working population, they may need to create novel forms of collective bargaining, where negotiations take place between the workplace and the union rather than with a particular employer or sector (International Labour Organization, 2017). The first unions of gig economy workers have recently formed in the UK (IWGB) and Argentina (Asociación de Personal de Plataformas (APP)) to collectively represent platform workers, and relatively informal coalitions of workers around internet-based communities might also hold promise (Wood, Lehdonvirta, & Graham, 2018). However, the diversity of these platforms is likely to result in variance in the power resources of platform workers, and there is some evidence of co-existence of trade unions, other unions and union-like organisations defending the needs and interests of platform workers (Vandaele, 2018).

As digital technologies allow the labour market to become more globalised than ever with multinational firms and platforms acting as large employers in various countries, the roles played by global trade union federations may be able to give workers a voice at the global scale at which transactions take place. Platform cooperatives could also be developed by groups of workers to widen ownership, foster democratic governance and promote solidarity in the economy (Scholz, 2016).

5. Data science research directions

The third section of this review addresses areas of innovative research applying data science approaches to investigate the emerging future of work research directions. This section discusses research findings around the following topics: the susceptibility of tasks and assignments to computerisation; industrial diversification and data-driven policy tools; and development of online labour markets. Taking note of the fact that many analyses on future of work vary in focus and timeframe (leading to disagreement and confusion), our review offers a constructive analysis of the approaches and methods that previous studies have taken and identifies empirical challenges to answering the key questions in the field.

5.1. Susceptibility of tasks and assignments to computerisation

Because the impact of technology and automation does not appear to be as quick or far reaching as some accounts have warned, developing a more granular sense of which jobs will be affected most or fastest could aid in managing the transition. An emerging body of research around measuring the susceptibility of jobs to computerisation has recently sprouted up and the approaches using data science are of particular interest.

In a widely-cited as well as rather debated paper, Frey and Osborne (2017) address this question with a methodology to categorise occupations according to their susceptibility to computerization. The authors draw upon machine learning and mobile robotics to design their methodology and estimate the probability of computerisation for 702 occupations while studying the expected impacts of future computerisation on the United States labour market.

The study was the first to move beyond explaining the impact of computerisation on routine tasks and investigate the impact of computerisation on occupational employment composition. In their methodology, the authors draw from recent developments in engineering sciences, in particular in machine learning, including data mining, machine vision, computational statistics and other sub-fields of AI as well as from mobile robotics to derive additional dimensions to analyse the susceptibility of jobs to computerisation. The authors develop the task model of Autor et al (D. H. Autor, Levy, & Murnane, 2003) further by identifying bottlenecks related to perception and manipulation tasks, creative intelligence tasks and social intelligence tasks. Their approach considers the problems engineers need to solve in order for certain occupations to be automated and categorises jobs according to the difficulty of the problems related to them. Matching the characteristics of these problems to occupational characteristics using data from O*NET, a service developed for the United States Department of Labor, the authors examine the future direction of technological change, including impact on the occupational composition, on the number of jobs at risk as well as the probability of computerisation, wages and educational attainment.

The authors find that 47% of total employment in the United States is in high risk of automation over the next decade or two. These include transportation, logistics, office and administrative support and production, which the authors note, are areas identified in previous studies to have high susceptibility for computerisation. In contrast to previous research, they also find that a large share of the service occupations is in similarly high risk of automation. Another finding is that wages and educational attainment have a strong negative relationship with the probability of computerisation. Interestingly, the authors state that the trend towards labour market polarisation is limited, as computerisation mainly affects low skill and low wage occupations, while low-skill workers reallocate to tasks that are not susceptible to computerisation—tasks requiring creative and social intelligence.

The findings of Frey and Osborne inspired several studies on the topic, many of which discovered similarly high-risk rates for the United States. A second series of papers moved away from a focus on occupations and instead analysed the automatability of tasks as more granular units making up occupations (Arntz, Gregory, & Zierahn, 2016; D. H. Autor, 2015). Using data from the Survey of Adult Skills (PIAAC), Artz, Gregory and Ziehran (2016) found the risk rates dropping significantly, including a 9% risk rate for the United States. In a study published as an OECD working paper, Nedelkoska and Quintini (2018) follow up on the second stream of research and estimate the risk of automation for individual jobs in 32 OECD countries using data from PIAAC. The data allows the authors to use a more disaggregated occupational classification and they argue this makes their analysis more closely aligned to the potential automation deriving from the development of machine learning. The authors also highlight the significant changes that jobs will undergo as a result of the adoption of new technologies and offer an analysis on the distribution of risk within different population groups and on the role that training can play in helping workers transit to new career opportunities.

The authors find that across the 32 countries, every other job is likely to be significantly affected by automation, but the degree of risk varies with only 14% of jobs being characterised as highly automatable (Nedelkoska & Quintini, 2018). They specify that the variance of automatability across countries is considerable: whereas 33% of jobs in Slovakia are highly automatable, only 6% in Norway are in high risk of automation. The authors discover that the risk of automation chiefly affects jobs in manufacturing and agriculture, although a number of service sectors, such as postal and courier services, land transport and food services are also found to be highly automatable. Unlike Frey and Osborne, the authors find that automation does not risk high-skilled occupations, and mainly affects low-skilled jobs. A novel finding is that the risk of automation is highest among teenage jobs. The authors describe the relationship between automation and age as U-shaped, but find that the peak in automatability among youth jobs is higher than the peak within senior workers. The authors maintain that automation is much more likely to result in youth unemployment, than in early retirements. Other studies using datasets measuring tasks found that approximately half of the work activities around the world could be automated, but the proportions that would actually be displaced would be likely smaller and range widely between countries (McKinsey Global Institute, 2017), and that the estimated fifth of affected UK jobs are likely to be replaced with new job creation (Hawksworth & Snook, 2018)).

While the emergent body of machine learning and machine robotics research around the susceptibility of jobs for computerisation has produced interesting and policy-relevant research findings, several areas have been highlighted for future work, including timing of the risk within different industries and countries, regional estimates of the risk of automation and regional concentration of risk, as well as consideration of the risk of automation in the context of research on wage polarization, inequality and redistribution of income.

5.2. Industrial diversification and data-driven policy tools

While the net effects of the re-organisation of work and automation on employment remains a topic of intense debate, there is expected to be significant regional variation driven by differences in sectoral susceptibility (Gregory, Salomons, & Zierahn, 2016). Data modelling approaches are needed to shed light on industrial and skills policy-making and recently a group of studies has taken a skills-based perspective to investigating industrial diversification and resilience. This work emerges from the fields of economic complexity and evolutionary economic geography, and focuses on the role of embedded knowledge in a place (Nelson, 1982; Frenken, Oort, & Verburg, 2007; C. Hidalgo & Hausmann, 2009). From this viewpoint, it is the tacit know-how embedded in workers that constrains the future development of a region. Hence, quantifying embedded knowledge in terms of complementary skills or capabilities (termed ‘economic complexity’ by Hidalgo and Hausmann, (2009)), and identifying new activities that are ‘proximate’ in terms of their skill and knowledge requirements (Frenken et al., 2007;

C. A. Hidalgo, Klinger, Barabási, & Hausmann, 2007), is key to the development of diversification and development strategies.

Within this framework, places move into new economic activities that share existing skills in a path dependent manner. This process may be modelled using a network where nodes represent industries and edges represent skill-overlap (C. A. Hidalgo et al., 2007; Neffke, Henning, & Boschma, 2011). This network can be seen as an 'economic landscape': the position of a place constrains its future development path. While centrally located regions (in terms of their existing industries—nodes—in the network) share skills with many potential new industries, peripheral regions have fewer options. Modelling diversification paths using industry networks is quite well-established in the 'related diversification' literature (Frenken et al., 2007; Neffke et al., 2011), and has been deployed to study a wide range of questions around local growth paths, including employment and export growth, and firm and sector entry and urban formality rates (Neffke et al., 2011; Hausmann et al., 2014; O'Clery, Gomez, & Lora, 2016).

In a paper published in 2011 Neffke, Henning and Boschma, using data from Sweden, investigate whether regions branch into industries that are technologically related to the pre-existing industries in the region. The authors study the regional growth paths of 70 Swedish regions from 1969 to 2002 with plant-level data, and develop an indicator of technological relatedness based on the co-occurrence of products that belong to different industries in the portfolios of manufacturing plants. Applying a network methodology, they build an 'industry space', a network graph that connects related industries, and derive estimates for technological relatedness and technological cohesion of regional industries. The authors couple their network analysis with a traditional regression methodology to investigate membership, entry and exit into an industrial portfolio of a region.

The authors find that the evolution of the economic landscape in Sweden is subject to strong path dependencies, as regions diversify by branching into industries that are related to their current portfolio of industries. However, industries that enter a region are less related to the local industrial portfolio than the average technological proximity among existing portfolio members. The authors also find that the probability of exit grows when industries are technologically less related to the region's portfolio and where technologically related industries are absent in the region. They argue that a network representation of industry relatedness, as seen via the industry space, gives rise to a powerful tool that can be used in case study analysis and regional policy-making, enabling policy makers to identify future threats and opportunities for the industrial development of their regions.

In a follow-on article published in 2013, Neffke and Henning proposed a new measure to capture the skill relatedness between industries. This measure aims to quantify the similarity of different industries' human capital or skill requirements, and uses data on cross-country labour flows in Sweden between 2004 and 2007 (Neffke & Henning, 2013). Following the network and econometric-based methodology developed in their earlier publication, the authors find that firms are more likely to diversify into industries that are linked to the firms' core activities in terms of similar skills than into industries without such similarity or into industries that are related through value chain linkages or by classification relatedness. The authors point out that research on skill relatedness can provide insights for both firm level and broader structural change, specifically around managing and leveraging human capital, and thus offers a powerful tool for both business and policy at the regional and national levels.

This network-based approach to studying economic dynamics and diversification has been expanded to shed light on new topics including that of urban labour informality within developing economies. O'Clery, Gomez, and Lora (2016) analyse the relationship between formal employment creation and the complexity of the local skill base using administrative datasets from the social security system of Colombia. Adapting a measure of industry sophistication previously proposed by Hidalgo and

Hausmann (2009), and the skill relatedness methodology of Neffke et. al. (2011), the authors find that workers tend to join the formal economy through low complexity industries in the network and are unlikely to transfer to more peripheral or inaccessible sophisticated industries. They propose a new metric, complexity potential, which captures the potential of a city to diversity into complex sectors that are closely related to the city's current skills. The authors show that this metric predicts the growth of formality rates across cities in Colombia more robustly than traditional indicators such as quality of governance, etc. They point out that these results give rise to various policy implications, including that in order to reduce informality in cities, productive skills should be nurtured to facilitate the development of more complex industries (O'Clery et al., 2016).

These recent research efforts to map technological and skill relatedness between industries, as captured by industry spaces, offer a novel methodological framework to study the diversification dynamics that are key for regions and countries adapting to and preparing for changes related to the future of work. A number of authors note that future research could extend their work in addressing the dynamics and national characteristics that industry spaces may have as well as investigate industry spaces internal to certain firms. Similarly, further work into regional growth paths, regional branching and regional resilience is suggested.

5.3. Development of the gig economy and online labour markets

The availability of work on and through digital platforms is one of the emergent characteristics of the changing nature of work. However, quantifying the volume and growth of this phenomenon is difficult, as conventional labour statistics don't trace work carried out through platforms and neither is its value easily reflected in the GDP (Reinsdorf & Quirós, 2018). Various research approaches to this domain of work have been deployed, including interviews of workers, usage of apps and analysis of platform transactions, many of which have focused on only one platform. Indexing and visualisation focused projects have recently sought to quantify the size of the online labour market.

Relying on public data, estimates and assumptions based on interviews with online labour firms and industry experts, Kuek et al (2015) estimated the size of the 'online outsourcing' market including microwork and online freelancing. The authors' approach consisted of a) collecting gross service revenue data from five leading microwork and online freelancing firms: Upwork, Freelancer, Zhubajie/Witmart, Amazon Mechanical Turk (MTurk) and CrowdFlower, b) estimating the share of the market controlled by these firms, and c) verifying and validating collected data against publicly available estimates. Following this approach, the study found that in 2013 there were 48 million registered workers of whom 10% were considered active and the gross service revenue within the industry amounted to $2 billion.

At the time of the study, MTurk and CrowdFlower dominated the market with a combined share of 80% of the entire microwork market and a combined annual global gross services revenue of $120 million. Various smaller platforms formed the rest of the market, including open services platforms, such as Microworkers.com and clickworker.com as well as managed services platforms such as Samasource and CloudFactory (Kuek et al., 2015). In comparison, the online freelancing market measured over 10 times larger with a combined annual global gross services revenue of $1.9 billion. The three leading freelancing firms Upwork, Freelancer, and Zhubajie/Witmart were estimated to form approximately half of the market. The authors didn't provide country-based estimates for the supply or demand of work on these platforms and mentioned that various factors limited the scope of their study, including poor data availability, uncertain growth trajectories due to the nascent nature of the industry and the uncertainty of long-term projections (Kuek et al., 2015).

An entirely transaction data-driven approach to measuring the online labour market was launched in 2016, when Kässi and Lehdonvirta created the Online Labour Index (OLI) that comprises an index and downloadable data (Kässi & Lehdonvirta, 2018b). The index measures the utilisation of online English-language labour platforms over time and across countries and occupations. The authors limit their coverage to platforms through which buyers and sellers of labour or services transact fully digitally, excluding platforms for local services, such as Uber and Airbnb, whose operations are confined to national borders and are conceptually quite different from online gig platforms (Kässi & Lehdonvirta, 2018a). The index is based on tracking all projects and tasks posted on a sample of the most popular platforms, using API access and web scraping.

The index has collected data for two years, and the authors estimate that it has grown about 21% (21 index points) from May of 2016 to mid-January 2018. It tracks the demand in different tasks and reveals that the highest demand is for software development and technology skills, which form roughly one third of the vacancies. The second highest demand is for creative and multimedia work, followed by clerical and data entry work. The index also provides a distribution of employers by country and occupation and shows that across occupations, roughly half of the vacancies are posted by employers from the United States and United Kingdom, India, Australia and Canada are amongst other prominent employer countries.

The authors find it surprising that employers from all of the leading buyer countries post most vacancies in the software development and technology category, even as the conventional domestic labour markets have highly divergent occupational profiles and sectoral and industry structures. However, they suspect that the similarity may be explained with the fact that the demand largely derives from the information technology industry. In the image below (see Figure 1) the vacancies tracked by the OLI are mapped by country for September 2016 (Ojanperä & Graham, 2016).

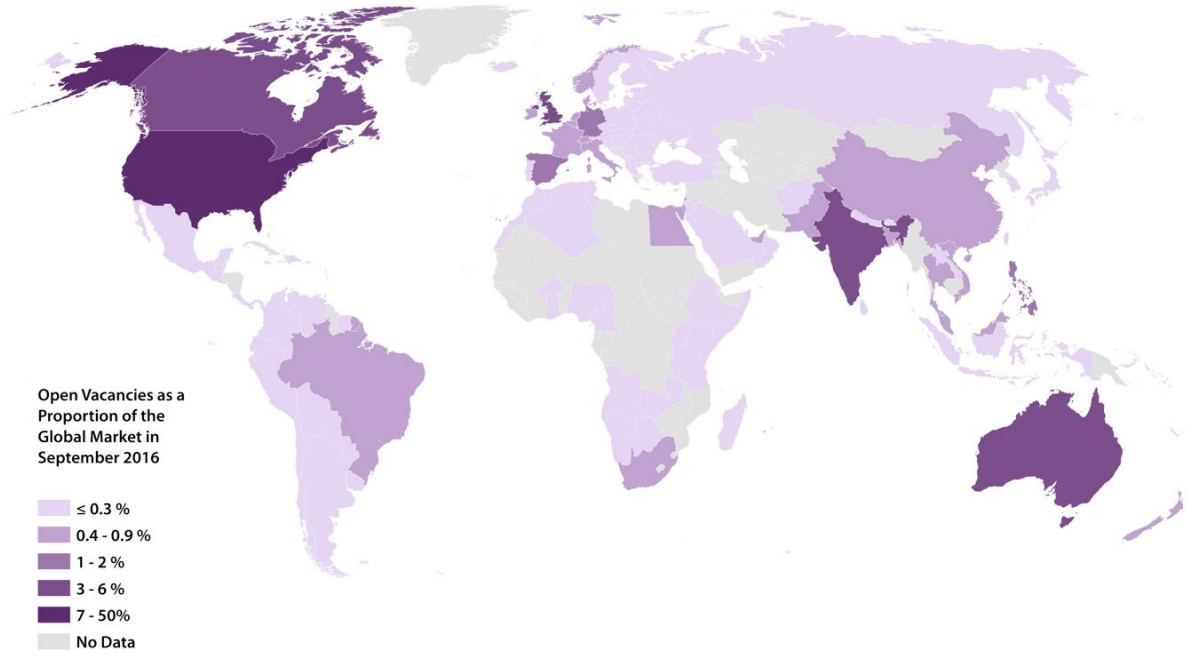


Figure 1. OLI labour demand in September 2016.

To measure the supply of labour, the authors created a Worker Supplement for the OLI, which works similarly, but observes workers on the included platforms. They found that the country with a largest supply of online labour is India, which accounts for roughly 25% of the workforce on these platforms. Bangladesh is home to 16% of the workers, while the United States hosts 12% of those working on the

included platforms. Countries have rather specified profiles in terms of the projects they carry out, and whereas Indian workers carry out 55% of projects related to software development and technology, the United Kingdom accounts for 22% of the professional services, including accounting, legal services and business consulting (Kässi & Lehdonvirta, 2018b). In the image below (see Figure 2) the workers tracked by the OLI are mapped by country for October 2017 (Ojanperä & Graham, 2018).

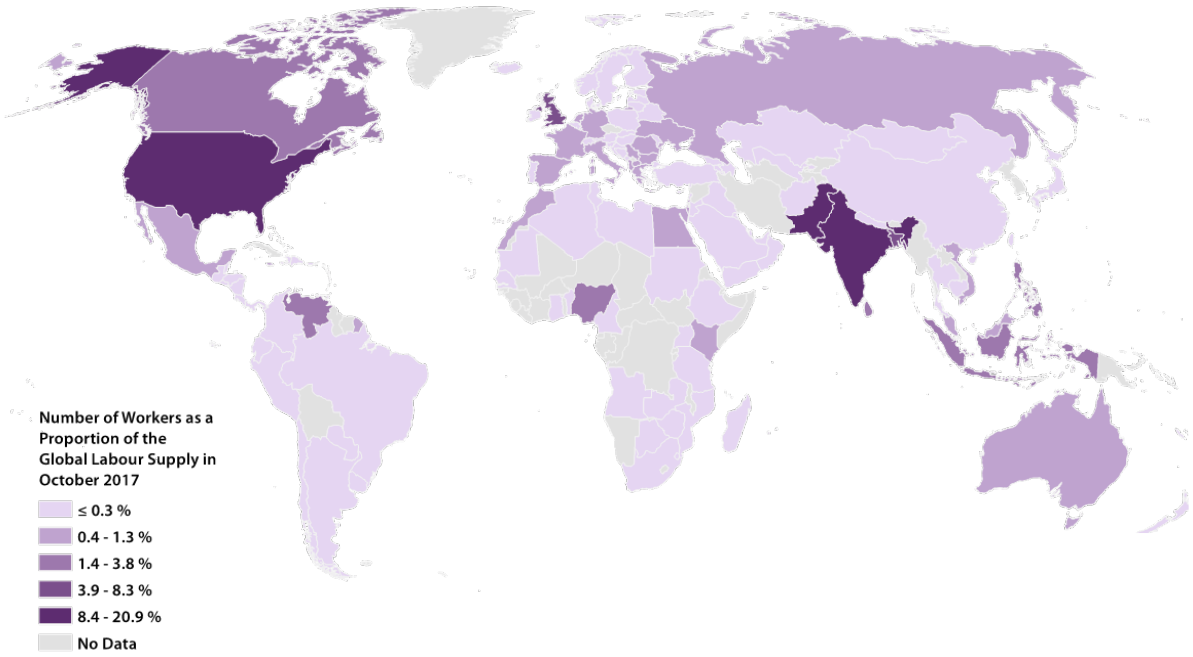


Figure 2. OLI labour supply in October 2017.

The digital economy is notoriously difficult to quantify and measure, and these approaches offer innovative ways to estimate activities in the digital labour market. Other research has focused on single local (Hall & Krueger, 2018; Berger, Chen, & Frey, 2018) or global (Horton, Kerr, & Stanton, 2017) platforms and only one other project is measuring a continuous pulse on the software development focused on MTurk (Difallah, Catasta, Demartini, Ipeirotis, & Cudré-Mauroux, 2015). Researchers at JP Morgan Chase Institute additionally analysed payments directed through 30 (Farrell & Greig, 2016) and 128 (Farrell, Greig, & Hamoudi, 2018) online platforms to Chase checking accounts. Partially because the platforms and activities in this domain are nascent, the existing platforms are in constant process of development, and new players enter the market each year, accounting for the size of the online workforce is challenging. Many of the platforms have developed highly individualised structures, including the algorithms that are used to match workers with employers thus adding to the challenges in estimating the volume and characteristics of activities within this domain.

6. Concluding remarks

This document has presented a review of the literature on the future of work. The first part of the review has summarised and discussed the main findings related to the broad concept of the future of work, including changes in the nature and creation of jobs, assignments and tasks; changing organisation of work and production; varying impacts of the changing nature of work on society; and the governance of these changes through politics, policy and institutions. The second section of the review has addressed emerging research directions and discussed the research findings around the following themes: potential drivers of the changing nature of work; disparate impacts of technology on different

tasks; challenges for young people to boost employability; impacts of the changing nature of work on the disenfranchised; and proposals for policies and governance models to manage the transitions related to the future of work. The third section has addressed areas of innovative research applying data science approaches and discussed the research approaches and findings around the susceptibility of tasks and assignments to computerisation; industrial diversification and data-driven policy tools; and development of online labour markets.

Because of rapid technological development, many commentators point to inevitable technological changes in the future of work. However, the overview that emerges from this review of the material suggests that multiple possible futures exist that depend on complex dynamics between context, choices and adaptability to new circumstances shaping the opportunities for individuals, firms, civil society organisations, governments and international organisations. Recent research on the topic has identified challenges, including rising inequality between and within countries, loss of jobs, hardship faced by younger generations and the disenfranchised and algorithmic control on the workplace.

However, the changing nature and organisation of jobs and the adoption of new technologies throughout the economy, also gives rise to new opportunities, such as new jobs in both technology-driven and traditional industries. Widening market access, better-suited models to govern and regulate the changing nature and organisation of work and improved workplace technology are other areas where changes may lead to positive outcomes. While these changes affect economies and societies differently around the world, the challenges and opportunities give rise to research opportunities and open up avenues for collaboration and learning. The changing nature and organisation of work and its diverse impacts on societies will need to be understood through not just best practice applied to new topics, but also emerging research approaches and themes rooted in data science and AI, such as machine learning, robotics and network science. As the future of work quickly becomes the present, there is an urgent need for scholarship that attempts to understand how to make our new world of work sustainable, equitable and just.

This review was commissioned by The Alan Turing Institute for the purpose of informing the Institute's research strategy aiming to further data science and AI research to address real-world problems. Using critical review method, this review has synthesised the key findings on future of work drawing from high-quality academic and policy literature and focusing on the state of knowledge, gaps in literature and avenues for future research.

Team members

This literature review was prepared by Sanna Ojanperä, a doctoral student and researcher at the Oxford Internet Institute, University of Oxford and doctoral student at The Alan Turing Institute and her thesis supervisors Dr Neave O'Clery, Senior Research Fellow at the Mathematical Institute, University of Oxford and Turing Fellow at The Alan Turing Institute and Prof Mark Graham, Professor of Internet Geography at the Oxford Internet Institute and Turing Fellow at The Alan Turing Institute.

Funding

Sanna Ojanperä is currently funded by The Alan Turing Institute doctoral grant TU/C/000020 and together with Mark Graham is working on a project investigating knowledge economies in Sub-Saharan Africa, which receives funding from the European Research Council (ERC-2013-StG335716-GeoNet). Mark Graham is also supported by the ESRC (ES/S00081X/1) and the Leverhulme Trust (PLP-2016-155) grants. Neave O'Clery receives funding from ESRC RCUK grant ES/P011055/1 focused on urban development.

[i] The Foundations 'fair work principles' that they intend to apply to platforms are available at: http://fair.work/

Bibliography

Acemoglu, D., & Autor, D. (2011). Skills, tasks and technologies: Implications for employment and earnings. *Handbook of Labor Economics*, *4*, 1043–1171.

Ajwad, M. I., Hut, S., Abdulloev, I., Audy, R., de Laat, J., Kataoka, S., … Torracchi, F. (2014). *The skills road: skills for employability in Tajikistan*. Washington, D.C., United States: The World Bank.

Arntz, M., Gregory, T., & Zierahn, U. (2016). The Risk of Automation for Jobs in OECD Countries. https://doi.org/10.1787/5jlz9h56dvq7-en

Autor, D. (2014). *Polanyi's Paradox and the Shape of Employment Growth* (Working Paper No. 20485). National Bureau of Economic Research. https://doi.org/10.3386/w20485

Autor, D. H. (2015). Why Are There Still So Many Jobs? The History and Future of Workplace Automation. *Journal of Economic Perspectives*, *29*(3), 3–30. https://doi.org/10.1257/jep.29.3.3

Autor, D. H., & Dorn, D. (2013). The Growth of Low-Skill Service Jobs and the Polarization of the US Labor Market. *American Economic Review*, *103*(5), 1553–1597. https://doi.org/10.1257/aer.103.5.1553

Autor, D. H., Levy, F., & Murnane, R. J. (2003). The Skill Content of Recent Technological Change: An Empirical Exploration. *The Quarterly Journal of Economics*, *118*(4), 1279–1333. https://doi.org/10.1162/003355303322552801

Baker, D. (2014). *Can Productivity Growth Be Used to Reduce Working Time and Improve the Standard of Living of the 99 Percent? The Future of Work in the 21st Century*. Economic Analysis Research Network.

Berger, T., Chen, C., & Frey, C. B. (2018). Drivers of disruption? Estimating the Uber effect. *European Economic Review*, *110*, 197–210. https://doi.org/10.1016/j.euroecorev.2018.05.006

Bernhardt, A. (2014). *Labor Standards and the Reorganization of Work: Gaps in Data and Research* (IRLE Working Paper No. 100–14). Retrieved from http://irle.berkeley.edu/files/2014/Labor-Standards-and-the-Reorganization-of-Work.pdf

Bodewig, C., Badiani-Magnusson, R., McDonald, K., Newhouse, D., & Rutkowski, J. (2014). *Skilling Up Vietnam: Preparing the Workforce for a Modern Market Economy*. Washington, D.C., United States: The World Bank.

British Academy, & The Royal Society. (2018). *The Impact of Artificial Intelligence on Work: An Evidence Synthesis on Implications for Individuals, Communities, and Societies*. London (UK), United Kingdom: The British Academy.

Brynjolfsson, E. (2016). *The second machine age: work, progress, and prosperity in a time of brilliant technologies* (New edition.). New York: WWNorton & Company.

Burke, M. (2017). An Uncertain Future. *Finance & Development*, *54*(2), 4–5.

Chen, M. A. (2012). *The Informal Economy: Definitions, Theories and Policies* (WIEGO Working Paper No. 1). Cambridge, MA: Women in Informal Employment: Globalizing and Organizing (WIEGO). Retrieved from http://wiego.org/publications/informal-economy-definitions-theories-and-policies

Coulibaly, S., Deichmann, U., Freire, M. E., Gill, I. S., Goh, C., Kopp, A. D., … Uchida, H. (2008). *World development report 2009 : reshaping economic geography* (No. 43738) (pp. 1–410). The World Bank. Retrieved from http://documents.worldbank.org/curated/en/730971468139804495/World-development-report-2009-reshaping-economic-geography

Difallah, D. E., Catasta, M., Demartini, G., Ipeirotis, P. G., & Cudré-Mauroux, P. (2015). The Dynamics of Micro-Task Crowdsourcing: The Case of Amazon MTurk. In *Proceedings of the 24th International Conference on World Wide Web* (pp. 238–247). Republic and Canton of Geneva, Switzerland: International World Wide Web Conferences Steering Committee. https://doi.org/10.1145/2736277.2741685

Djankov, S., La Porta, R., Lopez-de-Silanes, F., & Shleifer, A. (2002). The Regulation of Entry. *The Quarterly Journal of Economics*, *117*(1), 1–37. https://doi.org/10.1162/003355302753399436

Dorn, D. H. (2015). *The Rise of the Machines How Computers Have Changed Work* (UBS Center Public Paper No. 4).

Dorn, D. H., & Autor, D. H. (2013, August 24). How Technology Wrecks the Middle Class. Retrieved April 10, 2018, from https://opinionator.blogs.nytimes.com/2013/08/24/how-technology-wrecks-the-middle-class/

Farrel, D. and Greig, F. (2016). Paychecks, Paydays, and the Online Platform Economy: Big Data on Income Volatility. Retrieved from: https://www.jpmorganchase.com/corporate/institute/report-paychecks-paydays-and-the-online-platform-economy.html

Farrel, D., Greig, F. and Hamoudi, A. (2018). The Online Platform Economy in 2018: Drivers, Workers, Sellers, and Lessors. Retrieved from: https://www.jpmorganchase.com/corporate/institute/document/institute-ope-2018.pdf.

Fankhauser, S., Sehlleier, F., & Stern, N. (2008). Climate change, innovation and jobs. *Climate Policy*, *8*, 421–429.

Frenken, K., Oort, F. V., & Verburg, T. (2007). Related Variety, Unrelated Variety and Regional Economic Growth. *Regional Studies*, *41*(5), 685–697. https://doi.org/10.1080/00343400601120296

Frey, C. B., & Osborne, M. A. (2017). The future of employment: How susceptible are jobs to computerisation? *Technological Forecasting and Social Change*, *114*, 254–280. https://doi.org/10.1016/j.techfore.2016.08.019

Goldberg, P. K., Khandelwal, A., Pavcnik, N., & Topalova, P. (2008). *Imported Intermediate Inputs and Domestic Product Growth: Evidence from India* (Working Paper No. 14416). National Bureau of Economic Research. https://doi.org/10.3386/w14416

Gordon, R. J. (2014). *The Demise of U.S. Economic Growth: Restatement, Rebuttal, and Reflections* (Working Paper No. 19895). National Bureau of Economic Research. https://doi.org/10.3386/w19895

Graham, M., & Anwar, M. A. (2018). Digital Labour. In J. Ash, R. Kitchin, & A. Leszczynski (Eds.), *Digital Geographies*. London: Sage.

Graham, M., Hjorth, I., & Lehdonvirta, V. (2017). Digital labour and development: impacts of global digital labour platforms and the gig economy on worker livelihoods. *Transfer: European Review of Labour and Research*, *23*(2), 135–162. https://doi.org/10.1177/1024258916687250

Graham, M., & Woodcock, J. (2018). Towards a Fairer Platform Economy: Introducing the Fairwork Foundation. *Alternate Routes: A Journal of Critical Social Research*, *29*(0). Retrieved from http://www.alternateroutes.ca/index.php/ar/article/view/22455

Grant, M. J., & Booth, A. (2009). A typology of reviews: an analysis of 14 review types and associated methodologies. *Health Information & Libraries Journal*, *26*(2), 91–108. https://doi.org/10.1111/j.1471-1842.2009.00848.x

Gregory, T., Salomons, A., & Zierahn, U. (2016). *Racing With or Against the Machine? Evidence from Europe* (ZEW Discussion Paper No. 16–053). Retrieved from http://ftp.zew.de/pub/zew-docs/dp/dp16053.pdf

Guerreiro, J., Rebelo, S., & Teles, P. (2017). *Should Robots be Taxed?* (Working Paper No. 23806). National Bureau of Economic Research. https://doi.org/10.3386/w23806

Guihang, G., Qian, L., & Guangfan, L. (2014). Effects of Clusters on China's E-Commerce: Evidence from the Junpu Taobao Village. *International Journal of Business and Management*, *9*(6), 180. https://doi.org/10.5539/ijbm.v9n6p180

Hall, J. V., & Krueger, A. B. (2018). An Analysis of the Labor Market for Uber's Driver-Partners in the United States. *ILR Review*, *71*(3), 705–732. https://doi.org/10.1177/0019793917717222

Hausmann, R., Hidalgo, C., Bustos, S., Coscia, M., Simoes, A., & Yildirim, M. A. (2014). The Atlas of Economic Complexity: Mapping Paths to Prosperity. MIT Press.

Hawksworth, J., & Snook, R. (2018). *UK Economic Outlook*. London, United Kingdom: PwC United Kingdom.

Hidalgo, C. A., Klinger, B., Barabási, A.-L., & Hausmann, R. (2007). The Product Space Conditions the Development of Nations. *Science*, *317*(5837), 482–487. https://doi.org/10.1126/science.1144581

Hidalgo, C., & Hausmann, R. (2009). The building blocks of economic complexity. *Proceedings of the National Academy of Sciences*, *106*(26), 10570–10575. https://doi.org/10.1073/pnas.0900943106

Horton, J., Kerr, W. R., & Stanton, C. (2017). *Digital Labor Markets and Global Talent Flows* (Working Paper No. 23398). National Bureau of Economic Research. https://doi.org/10.3386/w23398

Hou, J., Gelb, S., & Calabrese, L. (2017). *The Shift in Manufacturing Employment in China* (Supporting Economic Transformation). The Overseas Development Institute. Retrieved from https://set.odi.org/wp-content/uploads/2017/08/SET-China_Shift-of-Manufacturing-Employment-1.pdf

International Labour Office. (2017). *Future of Work. Inception Report for the Global Commission on the Future of Work*. Geneva, Switzerland: International Labour Organisation.

International Labour Organization. (2017). *The Future of Work We Want: A Global Dialogue*. Geneva, Switzerland: International Labour Organization.

Kässi, O., & Lehdonvirta, V. (2018a). Online labour index: Measuring the online gig economy for policy and research. *Technological Forecasting and Social Change*. https://doi.org/10.1016/j.techfore.2018.07.056

Kässi, O., & Lehdonvirta, V. (2018b). The Online Labour Index | - The iLabour Project - University of Oxford. Retrieved from ilabour.oii.ox.ac.uk/online-labour-index/

Katz, L. F., & Krueger, A. B. (2016). *The Rise and Nature of Alternative Work Arrangements in the United States, 1995-2015* (Working Paper No. 22667). National Bureau of Economic Research. https://doi.org/10.3386/w22667

Kuek, S. C., Paradi-Guilford, C., Fayomi, T., Imaizumi, S., Ipeirotis, P., Pina, P., & Singh, M. (2015). *The Global Opoortunity in Online Outsourcing* (Transport and ICT). World Bank Group.

Lepanjuuri, K., Wishart, R., & Cornick, P. (2018). *The Characteristics of Those in the Gig Economy* (BEIST Research Paper No. 2). Department for Business, Energy & Industrial Strategy.

Levy, F., & Murnane, R. (2013). *Dancing with Robots: Human Skills for Computerized Work | MIT Department of Urban Studies and Planning*. Third Way. Retrieved from https://dusp.mit.edu/uis/publication/dancing-robots-human-skills-computerized-work

Maloney, W. F., & Molina, C. A. (2016). *Are automation and trade polarizing developing country labor markets, too ?* (No. WPS7922) (pp. 1–30). The World Bank. Retrieved from http://documents.worldbank.org/curated/en/869281482170996446/Are-automation-and-trade-polarizing-developing-country-labor-markets-too

Marcolin, L., & Squicciariani, M. (2017). *Investing in innovation and skills: Thriving in global value chains* (OECD Science, Technology and Industry Policy Papers No. 44). Organisation for Economic Co-operation and Development.

McKinsey Global Institute. (2017). *Where Machines Could Replace Humans and Where They Can't (Yet)*. London, United Kingdom: McKinsey Global Institute.

Michaels, G., Ashwini, N., & Van Reenen, J. (2014). Has ICT Polarized Skill Demand? Evidence from Eleven Countries over 25 years. *Review of Economics and Statistics*, *96*(1), 60–77.

Mishel, L., Schmitt, J., & Shierholz, H. (2013). *Assessing the Job Polarization Explanation of Growing Wage Inequality*. EPI–CEPR Working Paper.

Moore, P. (2018). *The Threat of Physical and Psychosocial Violence and Harassment in Digitalized Work*. Geneva, Switzerland: International Labour Office.

Nedelkoska, L., & Quintini, G. (2018). *Automation, skills use and training* (OECD Social, Employment and Migration Working Papers No. 202). Retrieved from https://www.oecd-ilibrary.org/employment/automation-skills-use-and-training_2e2f4eea-en

Neffke, F., & Henning, M. (2013). Skill relatedness and firm diversification. *Strategic Management Journal*, *34*(3), 297–316. https://doi.org/10.1002/smj.2014

Neffke, F., Henning, M., & Boschma, R. (2011). How Do Regions Diversify over Time? Industry Relatedness and the Development of New Growth Paths in Regions. *Economic Geography*, *87*(3), 237–265. https://doi.org/10.1111/j.1944-8287.2011.01121.x

Nelson, R. R. (1982). *An evolutionary theory of economic change*. Cambridge, Mass ; London: Belknap Press of Harvard University Press.

O'Clery, N., Gomez, A., & Lora, E. (2016). The Path to Labour Formality: Urban Agglomeration and the Emergence of Complex Industries. *Center for International Development Working Paper*, *78*. Retrieved from https://growthlab.cid.harvard.edu/files/growthlab/files/rfwp_78.pdf

OECD. (2012). The Jobs Potential of a Shift Towards a Low-Carbon Economy. https://doi.org/10.1787/5k9h3630320v-en

OECD. (2017). *OECD Employment Outlook 2017*. Paris, France: OECD Publishing. Retrieved from http://www.oecd.org/els/oecd-employment-outlook-19991266.htm

Ojanperä, S., & Graham, M. (2016). Mapping the Availability of Online Labour — Oxford Internet Institute. Retrieved May 29, 2018, from http://dig.oii.ox.ac.uk/2016/10/20/mapping-the-availability-of-online-labour/

Ojanperä, S., & Graham, M. (2018). Mapping the Availability of Online Workers — Oxford Internet Institute. Retrieved October 29, 2018, from https://geonet.oii.ox.ac.uk/blog/mapping-the-availability-of-online-workers/

Olsen, L. (2009). *The Employment Effects of Climate Change and Climate Change Responses: A Role for International Labour Standards?* (GURN Discussion Paper No. 12). Geneva, Switzerland: International Labour Organization.

Perry, G., Maloney, W. F., Arias, O., Fajnzylber, P., Mason, A., & Saveedra-Chanduivi, M. (2007). *Informality : Exit and Exclusion*. Washington, DC, USA: World Bank. Retrieved from https://openknowledge.worldbank.org/handle/10986/6730

Reinsdorf, M., & Quirós, G. (2018). *Measuring the Digital Economy* (Measuring the Digital Economy). Washington D.C.: International Monetary Fund.

Riad, N. (2017). Education for LIfe. *Finance & Development*, *54*(2), 16–19.

Sachs, J. D., & Kotlikoff, L. J. (2012). *Smart Machines and Long-Term Misery* (NBER Working Papers No. 18629). National Bureau of Economic Research, Inc. Retrieved from https://ideas.repec.org/p/nbr/nberwo/18629.html

Scholz, T. (2016). *Platform Cooperativism: Challenging the Corporate Sharing Economy*. New York: Rosa Luxemburg Stiftung.

Science must examine the future of work. (2017). *Nature*, *550*(7676), 301. https://doi.org/10.1038/550301b

Srnicek, N. (2016). *Platform Capitalism*. Cambridge, UK ; Malden, MA: Polity Press.

Stiglitz, J. E. (2013). *The price of inequality* (Paperback edition.). London: Penguin Books.

Sudakov, D., Luksha, P., Strietska-Ilina, O., Gregg, C., Hofmann, C., & Khachatryan, L. (2016). Skills Technology Foresight Guide. International Labour Organization.

Sundararajan, A. (2017). The Future of Work. *Finance & Development*, *54*(2), 6–11.

Tabatabai, H. (2012). From Price Subsidies to Basic Income: The Iran Model and Its Lessons. In K. Widerquist & M. Howard (Eds.), *Exporting the Alaska Model: Adapting the Permanent Fund Dividend for Reform around the World* (pp. 17–32). New York: Palgrave Macmillan.

Taylor, M., Marsh, G., Nicol, D., & Broadbent, P. (2017). *Good Work: the Taylor Review of Modern Work Practices*.

The Roosevelt Institute. (2015). *Technology and the Future of Work: The State of the Debate*. Open Society Foundations.

World Bank. (2019). *World Development Report 2019: The Changing Nature of Work*. Washington D.C.: World Bank.

UNCTAD. (2017). *Information Economy Report 2017: Digitalization, Trade, and Development*. UNCTAD. Retrieved from http://unctad.org/en/PublicationsLibrary/ier2017_en.pdf

Valerio, A., Sanchez Puerta, M. L., Tognatta, N., & Monroy-Taborda, S. (2016). *Are There Skills Payoffs in Low- and Middle-Income Countries? Empirical Evidence Using Step Data* (World Bank Policy Research Working Paper No. 7879). Washington, D.C., United States: The World Bank.

Vandaele, K. (2018). *Will trade unions survive in the platform economy? Emerging patterns of platform workers' collective voice and representation in Europe* (No. 2018.05). Brussels: European Trade Union Initiative.

Wiesmann, B., Snoei, J. R., Hilletofth, P., & Eriksson, D. (2017). Drivers and barriers to reshoring: a literature review on offshoring in reverse. *European Business Review*, *29*(1), 15–42. https://doi.org/10.1108/EBR-03-2016-0050

Wood, A. J., Graham, M., Lehdonvirta, V., & Hjorth, I. (2018). Good Gig, Bad Gig: Autonomy and Algorithmic Control in the Global Gig Economy. *Work, Employment and Society*, 0950017018785616. https://doi.org/10.1177/0950017018785616

Wood, A. J., Lehdonvirta, V., & Graham, M. (2018). Workers of the Internet unite? Online freelancer organisation among remote gig economy workers in six Asian and African countries. *New Technology, Work and Employment*, *33*(2), 95–112. https://doi.org/10.1111/ntwe.12112

Yeung, Y., & Howes, S. (2015). *Resources-to-Cash: A Cautionary Tale from Mongolia* (Development Policy Centre Discussion Paper No. 42). Canberra: Australian National University. Retrieved from https://im4dc.org/wp-content/uploads/2015/09/Combined-Yeung.pdf

turing.ac.uk
@turinginst