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The impact of the technological revolution on labour markets and income distribution

CONTENTS

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Executive Summary

There are many concerns that technological innovation will lead to increased unemployment, suppressed wages and greater inequality. However, the impact of the new technologies on labour markets and income distribution is not predetermined. The right policy mix and institutional arrangements can ensure that the benefits of innovation are shared broadly, an essential step to achieving the Sustainable Development Goals (SDGs) for all. This work provides an evidence-based analysis of the link between recent technological progress, labour markets and inequality.

The promise and pitfalls of technological progress

Technological progress is a main driver of aggregate economic growth and improvements in living standards over the long term. It increases overall productivity, thereby boosting per capita income and consumption. While technological progress has mostly been incremental and gradual over time, on a few occasions, technological change has been revolutionary, transforming the organizational structure of societies and economies. For instance, mechanization and productivity gains from technology led to large declines in agricultural employment and the reorganization of economies and societies around industrial and urban centers. However, for this to happen, breakthrough technological inventions alone are not sufficient, as diffusion of new technologies is critical.

Now again, technologies are encroaching in areas where human abilities were once deemed indispensable, threatening to do for cognitive ability what machines did for muscle power. The pace of breakthroughs in several clusters of technology—from gene editing to machine learning and advanced materials—may signify that a new technological revolution is at hand, which could be transformative for almost every industry and every country.

The growing ability of artificial intelligence (AI) systems to autonomously solve complex problems could fundamentally reshape our economy and society, for example by developing new forms of transportation or revolutionizing health care. Additive or 3D manufacturing has the potential to change how products are made and to address many of the problems of industrialisation in disadvantaged countries, such as least developed countries (LDCs).

Just as these new technologies hold immense promise, they are also seen as a threat, potentially disrupting labour markets and contributing to income inequality. The biggest public fear is that robots and AI will replace human jobs on a large scale, resulting in mass unemployment or underemployment—and, consequently, widespread impoverishment—around the globe. In fact, labour has been losing its share of income. An ever-increasing inequality between technology owners and workers could lead to protracted social conflict.

The destruction, transformation and creation of jobs

Estimates of the share of jobs at risk to being automated vary widely and can reach staggering numbers of over 80 per cent. Most analyses suggest that AI and other new technologies will continue to benefit higher-skilled workers with a high degree of flexibility, creativity, and strong problem-solving and interpersonal skills. Low- and medium-skilled workers, both in manual and cognitive jobs, are expected to face further pressures from ever more capable machines and AI software. This could exacerbate the decline of middle-skilled jobs and rising wage inequality observed in the recent past, particularly in many developed countries. However, it is also possible that future AI-powered robots could increasingly displace highly educated and skilled professionals, such as doctors, architects and even programmers.

While there is no reason to downplay the impact of new technologies on labour markets and inequality, technology-induced unemployment rates of 80 per cent are not part of realistic future scenarios. Technologies replace certain tasks rather than complete occupations and, often ignored, new technologies also create jobs and demand new skills from workers. Throughout history, technological innovations have enhanced the productivity of workers and created new products and markets, thereby generating new jobs in the economy. This will be no different for AI, 3D printing and robotics.

Both job destruction and job creation are determined not only by technological feasibility, but also by economic, legal, regulatory or socio-political factors. The mere possibility that a job could be eliminated does not mean it will be eliminated. Firms will weigh the benefits of new automation technologies (for example, a lower wage bill or higher productivity) against their costs.

In fact, low wages partly explain why most developing countries with abundant cheap labour have so far not been visibly affected by automation. There are also immense legal and regulatory issues. For AI to be deployed on a large scale in healthcare, for example, it must be decided whether the doctor or the artificial intelligence will be responsible for claims of medical malpractice.

The current technological changes also contribute to a shift away from traditional work arrangements to "contingent work". While this increases worker flexibility and gainful employment opportunities, many non-standard work arrangements lead to precarious work relations, with workers having to bear employment and income risks by themselves.

In assessing the impact of new technologies, it is important to understand how technology interacts with other important trends. Changes in market structure—leading to increased monopolistic rents and high profits made by relatively few firms—are a key factor for explaining rising inequality in many countries. However, profit shares are not only rising in technology markets characterized by 'superstar firms' but also in other sectors, which points to the importance of regulatory policies and lobbying activities. Global value chains (GVCs) are driven both by technological advances and by changes in trade and investment policies. They have spurred trade and employment in several developing countries, though reshoring could limit this in the future.

Automation, enabled by new technologies, is accelerating not only in developed countries, but also in those developing countries that have established themselves as leading players in global manufacturing. At the same time, many LDCs do not yet possess the required skills, energy infrastructure, broadband or transport networks to take advantage of the new production techniques. Hence, one of the biggest risks and international challenges is that a new technological revolution will cause gains from manufacturing and participation in GVCs to become even more concentrated, limiting the scope for structural transformation in countries left behind.

Conclusions and the way forward

Overall, technological innovation is a main engine of productivity growth, but can also be a major force of disruption. The influence of technology on economies is not preordained, but can be shaped by policies at the local, national, and global levels. Rather than taking a passive wait-and-see approach, Governments as well as the United Nations can and should influence these processes. The general policy stance should be to embrace and direct these new technologies. Rather than trying to block them out of fear of disruption, policy makers should adopt appropriate and flexible regulatory and legal policies and promote national capacities to innovate.

At the same time, proactive policies are needed to ensure that the gains are broadly shared and displaced workers receive support. If technology changes the nature of work and disrupts traditional social insurance systems, policies can reduce vulnerabilities by expanding social protection systems. If technology leads to less equal income distribution, policies are called to redistribute income. If new technologies change the nature of skills demanded on labour markets, curriculums in schools and universities can be adapted and on-the-job and life-long learning opportunities can be promoted.[1]

National policies should be complemented by regional and global actions to address problems that are transnational in nature. Technological progress should not be used as an excuse for policy inaction, but rather as an incentive to find better solutions.

1 See (ILO 2011, pg. 35) for some examples of funding allocated to retrain workers to meet the new demand for skills.

1 Introduction

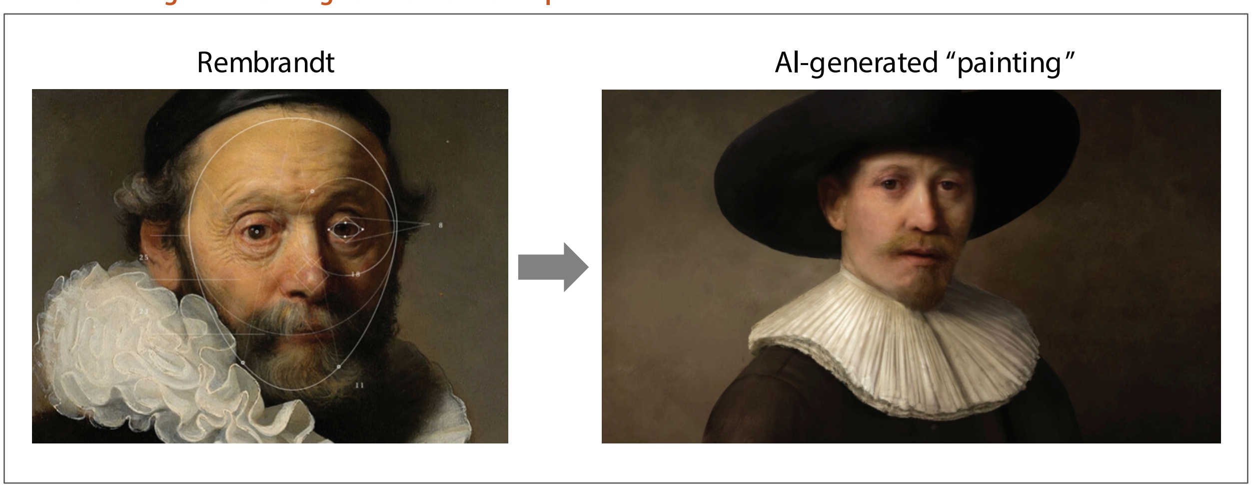
In April 2016, an artificial intelligence (AI) system was tasked with creating an artistic masterpiece. Using advanced machine learning algorithms and Rembrandt's entire body of work, the system learned the subject, colours, composition, dress, proportions, and even the brushstrokes of the 17th century master. After a computer made the design, the painting was created by a 3D printer. The result is a convincing, if unoriginal, work that showcases the advances in AI[2] and the growing capacity of machines to compete with humans, even in areas believed to be truly human in nature, such as the arts. However, since the painting hasn't been able to fetch the prices of a real Rembrandt, it also symbolizes the fact that machines are still missing a key component that is essential for them to become more than tools.

Even if a computer can't yet rival Rembrandt, the growing ability of AI systems to autonomously solve complex problems is one example of the ways in which new technologies have the potential to fundamentally reshape our economy and society. The pace of breakthroughs in several clusters of technology may signify that a new technological revolution is at hand. What some describe as the Fourth Industrial Revolution (4IR) is characterized by qualitatively and quantitatively different technologies and capabilities that could become transformative for almost every industry and every country.

Just as these new technologies hold immense promise, they are also seen as a threat, potentially disrupting labour markets and contributing to (income) inequalities. The most extreme concern is that automation, robots, and AI-based technologies will replace human jobs on a large scale, resulting in mass unemployment—and, consequently, widespread impoverishment—around the globe. Such concerns are not new. Since the first industrial revolution in the early 19th century, there have been several episodes of widespread anxiety over the job-destroying effects of technology.

What has received much less public attention are the direct and indirect job-creating effects of new technologies. Throughout history, technological innovations have enhanced the productivity of workers and created new products and markets, thereby generating new jobs. As argued below, this will be no different for AI, 3D printing and robotics. New jobs across all sectors of the economy will be created,

Figure 1.1
Artifical intelligence learning to create a masterpiece



Source: nextrembrandt.com

2 Details about this experiment can be found at www.nextrembrandt.com.

with entirely new professions expected to emerge in the longer-run.

If history is a guide, the new breakthrough technologies will not weaken—and could instead reinforce—the overall demand for human labour in the long run. The short-run disruptions to industries, sectors and businesses could, however, be immense. Continuing the trend of the Digital Revolution, 4IR is expected to result in a further automation of manufacturing and services. Most likely, these shifts will benefit high-skilled workers with a high degree of flexibility, creativity, and strong problem-solving and inter-personal skills. Low and medium-skilled workers, both in manual and cognitive jobs, are expected to face further pressures from ever more capable machines and AI software.

The transformation of industries and labour markets could have important consequences on global production patterns and jeopardize opportunities for low-income countries to catch up. One of the biggest risks and international challenges is that the gains from manufacturing and participation in global value chains become even more concentrated.

Where and in what form 4IR affects different economies will not only depend on technological possibilities, but also on economic, legal, regulatory, and socio-political questions. In this context, the role of government policies and institutions is crucial. The influence of technology on economies is not preordained, but can be shaped by policies at the local, national, and global levels. Rather than taking a passive wait-and-see approach, Governments as well as the United Nations can and should influence these processes. The general policy stance should be to embrace and direct these new technologies, rather than trying to block them out of fear of disruption. At the same time, proactive policies are needed to ensure that the gains are broadly shared and displaced workers receive support.

This work provides a detailed analysis of the link between recent technological progress, labour markets and inequality. Section 2 sets the stage by describing some of the key technologies and their potential for transforming economies and societies. Section 3 looks at past technological revolutions, with a focus on trends in productivity, employment and inequality. Section 4 discusses in detail the mechanisms that connect technological progress, labour markets, and income inequality. Section 5 looks ahead at possible scenarios for the coming decades. Section 6 concludes by identifying areas of priority for policymakers as they grapple with the effects of rapid technological change.

2 A new technological revolution?

In setting the stage for the remainder of this paper, this section introduces the concepts of technological progress and technological revolutions. It sets out to explain how incremental progress, under the right set of conditions, may revolutionize economies and societies. This section also introduces some of the technologies and breakthroughs that underpin the arguments that we are in the midst of a new technological revolution.

A. Technological progress and revolutions

Technological progress is a main driver of economic growth and improvements in living standards. It increases productivity, thereby boosting per capita income and consumption. Technology also influences the nature and quality of work, as well as the structure of societies. Of note, past literature has shown that technology, institutions and society tend to evolve together (Geels 2005).

The diffusion of technological progress has mostly been incremental and gradual over time, involving improvements and adaptations of existing technology. However, on a few occasions, technological change has been "radical", resulting in major breakthroughs that, under the right circumstances, have ultimately transformed the organizational structure of societies and economies (Freeman and Perez

1988). In each of these cases, key breakthroughs became transformative due to the right economic, social, and institutional conditions that made the adoption of new technologies viable.

The first industrial revolution was characterized by the growing use of machines to replace manual labour, particularly the use of the steam engine and new industrial methods organized in factories. The second revolution was marked by the rapid adoption of electricity and other technologies in manufacturing and was enabled by growing transportation, communication, and public health infrastructure. A third revolution came from the digitalization of electronics, which enabled information to play a transformative role in the social, economic, and political spheres.

Technologies become transformative when they evolve into general purpose technologies (GPTs) that enable productivity gains across many sectors of the economy.[3] In particular, past waves of industrialization have been associated with pervasive GPTs that resulted in growing returns-to-scale (Bresnahan and Trajtenberg 1995). The adoption of steam to power machines, the discovery and use of electricity, and the ease of communication permitted by information and communication technologies (ICT) are examples of applications of GPTs that were at the center of the three great disruptive periods in modern economic history. At each time, the GPTs contributed to fundamental economic transformation and helped reshape the world (Ng 2017).

However, the diffusion of GPTs often takes a long time, given that their adaptation requires complementary changes in physical infrastructure, as well as institutional, social and organizational changes. The steam engine was only widely diffused once the combination of abundant energy and expensive labour made the technology more attractive for a growing number of industries. The speed of adoption and diffusion of technology in an economy depends on a wide range of factors, including maturity, cost, and an enabling social, economic, and regulatory environment. It is also influenced by the ability of entrepreneurs to bring the technology into the market (NASEM et al. 2017, pg. 22).

Recent breakthrough developments in several clusters of technologies have led some to argue that a new technological revolution may now be taking place. A so-called Fourth Industrial Revolution (4IR) builds strongly on ICT expansion initiated during the digital revolution, but is characterized by qualitatively different technologies and capabilities.

Breakthroughs in many areas, including digital-tech, bio-tech, nano-tech, neuro-tech and green-tech,[4] have been spurred by the growing ability of artificial intelligence (AI) systems to autonomously solve complex problems (Davis 2017). This has been made possible by the combination of increasing computational power at decreasing costs, rapidly growing datasets, and advances in "deep learning" algorithms.

The combination of new technologies and the conditions that allow their widespread use can, as in past revolutions, transform labour markets and societal structures and vice versa (UN DESA 2016).

Artificial intelligence as a transformative technology

Rapid progress in AI is being seen as a key enabler of the transformative power of existing and new technologies on economic systems. The World Economic Forum characterized artificial intelligence as the cornerstone of the 4IR and many others consider the growing ability of software-based systems to mimic aspects of human intelligence as a historic development in the automation process (Schwab 2016). Once designed and deployed, modern AI can form its own rules to interpret new data and design solutions with minimal or no human participation. Whereas the steam engine was applied to tasks that required muscle power, AI is being applied to tasks that require brainpower (The White House 2016, pg. 8).

3 See Bresnahan (2010) for a survey of the literature on general purpose technologies.

4 United Nations (2016, chapter 3).

AI has been used commercially since the mid-1990s to assist in a variety of decision-making tasks, such as fraud detection. These early systems were a set of manually programmed rules that formed a decision-making process. Progress in AI has accelerated rapidly since around 2010, driven by the confluence of three factors: the growing availability of large datasets from commerce, social media, science, and other sources; the development of better machine learning algorithms and techniques (such as "deep learning"); and continued gains in computational power.[5]

As a result, AI abilities are growing rapidly. Machine learning has enabled AI to defeat the best human chess and Go players, and has proven to be useful in interpreting medical data, in facilitating communication, in developing new forms of transportation, and in industrial automation. AI capabilities have also greatly improved in the fields of computer vision, speech recognition, motor control (robots), language translation, and decision-making processes.

AI algorithms have outscored humans in identifying objects and faces in two popular tests (Aron 2015). This performance is, however, limited to certain categories as humans can still identify a much larger number of categories and infer context and other aspects of images. The challenge in further developing AI is in building algorithms that can draw inferences about the wider context, including what the images say about what may happen next.

In healthcare, AI and other digital technologies promise to change how data is captured and shared between patients and providers, providing support to diagnostic and clinical decisions. The use of electronic health records has already demonstrated improvements in the quality of care in the Veterans' Hospital Administration of the United States, for example. Deploying additional advanced technologies can further expand these efficiencies. AI can leverage data to predict readmission rates, infection risks, and other complications from treatment options to complement humans and help minimize preventable errors. Image analysis algorithms promise to assist pathologists and radiologists in interpreting data. Health and wellness can be promoted with large-scale access to behavioural data in wearable devices (NASEM et al. 2017, pg. 24).

AI has proven to be transformative in many areas, but the techniques in use result in AI that is "narrow" in its applications, allowing algorithms to master a single domain each time. Combined with sufficient data and the computing power to process it, existing techniques allow for the optimization of defined tasks. Some visible examples include winning a game like chess, or maximizing accuracy in translating text or understanding speech, or even the safe manoeuvring of a car from point A to point B. The predictions of the imminent development of a general-purpose AI—capable of creativity, planning, and other inherently human characteristics—rely on the extrapolation of recent exponential growth trends. While this remains a possibility, some experts assert, "[t]here are simply no known engineering algorithms for it. And I don't expect to see them any time soon" (Lee 2017).

Other technological breakthroughs

Technological frontiers now span many areas of materials, mechanics, and digital systems. There have been recent breakthroughs in manipulating atomic or molecular structures to improve the physical properties of materials. New gene-level techniques allow for the manipulation of biological systems, including the human genome. Progress in digital areas include advancements in information technology and computing, data analytics, and virtual and augmented reality, to name just a few (United Nations 2016). For manufacturing, improvements in robotic process automation have benefitted from progress in artificial-intelligence-endowed robotics (see table 2.1). While individually impressive, it is the combination of these many advances and new breakthroughs that can unlock even more transformative technological change.

5 Machine learning refers to algorithms that improve through experience by identifying patterns from data and continuously testing and adjusting the solution. This requires large datasets and computational power.

Table 2.1
Key differences between automation and artificial intelligence

<table>
<tr><th colspan="2">Types of automation and AI</th><th colspan="2">What they can do</th></tr>
<tr><td colspan="2">Robotic process automation</td><td colspan="2">Repetitive; Rules-based work.</td></tr>
<tr><td rowspan="3">Artificial Intelligence (AI)</td><td>Applied AI</td><td rowspan="2">Judgement-based processing</td><td>“Thinking”</td></tr>
<tr><td>General AI, machine-learning</td><td>“Learning”; improves over time. Example: natural language processing to understand human communication.</td></tr>
<tr><td>Synthetic, computer-based (“runaway”) AI</td><td colspan="2">Decision-making; learning; doing; independent creation and improvement of AI without a need for human intervention.</td></tr>
</table>

Source: Division for Sustainable Development, UN/DESA.
Note: All the technologies listed in the table can be either physical or virtual.

Manufacturing is also being transformed by advances in technologies such as 3D printing (or “additive manufacturing”), that can drastically alter the way physical goods are produced. 3D printing offers many benefits over traditional forms of manufacturing, including faster prototyping of designs, the ability to make complex and customized items, and the ability to quickly change a design (The Economist 2017). 3D printing works by adding material one layer at a time based on a digital set of instructions. Traditional manufacturing, in contrast, builds items by either moulding or removing material through cutting, drilling or milling.

Advances in additive manufacturing have enabled more rapid and precise “printing” of the desired shape using, for example, ultraviolet light to harden the material at each successive layer. This process is much faster than the traditional method of melting a material and depositing it in successive layers. It also should produce stronger and better-shaped materials given the chemical nature of the printing process.

Additive manufacturing reduces the time between design and production and allows for quick changes to the item and for customization. It also doesn’t require economies of scale in the same way as building a process around moulding does. Rather than requiring the manufacture of many identical items, 3D printing can be profitable even if individual items are customized since the changes occur in software. For metal parts, 3D printing allows for more complex shapes that may be nearly impossible with traditional methods, reducing the need for welding, for example. This is attractive for customized or high performance items used in niche applications. Additionally, items can be ordered as needed and produced in the best available location, obviating the need for large inventories.

B. Economic potential of the new technological breakthroughs

New technological breakthroughs can have both positive and negative effects on labour markets and social structures (see section 4 for more details). On one hand, the more pervasive use of technology enhances the productivity of workers and creates new products and markets, thereby creating new jobs. On the other hand, the use of technology also allows for greater automation, replacing human labour for certain tasks. In an extreme scenario, widespread automation enabled by advanced technologies could cause widespread unemployment and social upheaval. The net effect of both these opposing forces on labour market conditions can vary widely depending on the type of technology, the speed of its diffusion, and country-specific conditions, policies and institutions.

An optimistic view of the economic potential of technologies like AI relies on the extensive historical record of technological progress and the gains brought to human labour and living standards. This optimism is based on a long-term perspective and relies on the aggregate benefits of technological progress. For example, Mokyr et al. (2015) surveyed the historical lessons learned since the industrial revolution in the late 18th century and argued that, as occurred before, a greater use of computers and robots, enabled by rapid technological progress, will facilitate the creation of new products and services. These product innovations will lift productivity and GDP growth, thus creating new occupations on a large scale.

However, the effect on aggregate productivity of more sophisticated forms of AI and other breakthroughs is not yet evident in the data (see section 3). This may demonstrate that the influence of AI and other rapid breakthroughs currently remains limited to certain industries and production processes due to the lag between when the technology is developed and when it makes economic sense to use it broadly.

The pessimistic view about the link between technological progress and employment has two central points. First, despite the beneficial long-term effects of technological progress, the periods of transition involved deep changes to societies and to the nature of work, with many losing jobs and livelihoods. In other words, the Luddites[6] were right insofar as machines did indeed replace the role of the skilled textile artisan. Second, the pessimistic view argues that this time is different, and worse: the nature and pace of current technological progress is such that economies will not be able to generate a sufficient number of new jobs to prevent massive unemployment or underemployment.[7]

There are a growing number of studies which attempt to estimate the number of jobs that are susceptible to automation, with findings ranging from over 80 per cent to less than 10 per cent of total jobs (see section 5.B). The wide variation is the result of the different methodologies and assumptions used in each study, as well as individual country factors. Studies that treat an entire job as a monolithic activity tend to find that more jobs are susceptible to automation. Studies that instead consider jobs to be a combination of various tasks with varying degrees of susceptibility to automation find much lower estimates. The wide range of estimates on the potential impact of AI on jobs highlights the uncertainty workers and countries face when trying to confront and manage the risk of job losses from technological progress (see section 5 for more details).

The actual impact of technological change on jobs will depend on the economic response to the change in labour and capital costs, as well as on the interplay of technologies, industry characteristics, trade policies, institutions and labour market conditions. The organization of jobs around few or multiple tasks will have a large influence on the result, as well as the relative factor costs and the incentives for businesses to adopt capital and technology to replace labour (see section 4 for a full discussion).

3 Long term and recent trends

This section highlights how the previous industrial revolutions fundamentally transformed labour markets and the nature of work around the world, including trends in sectoral employment and the participation of women in the labour force.

A. Productivity trends

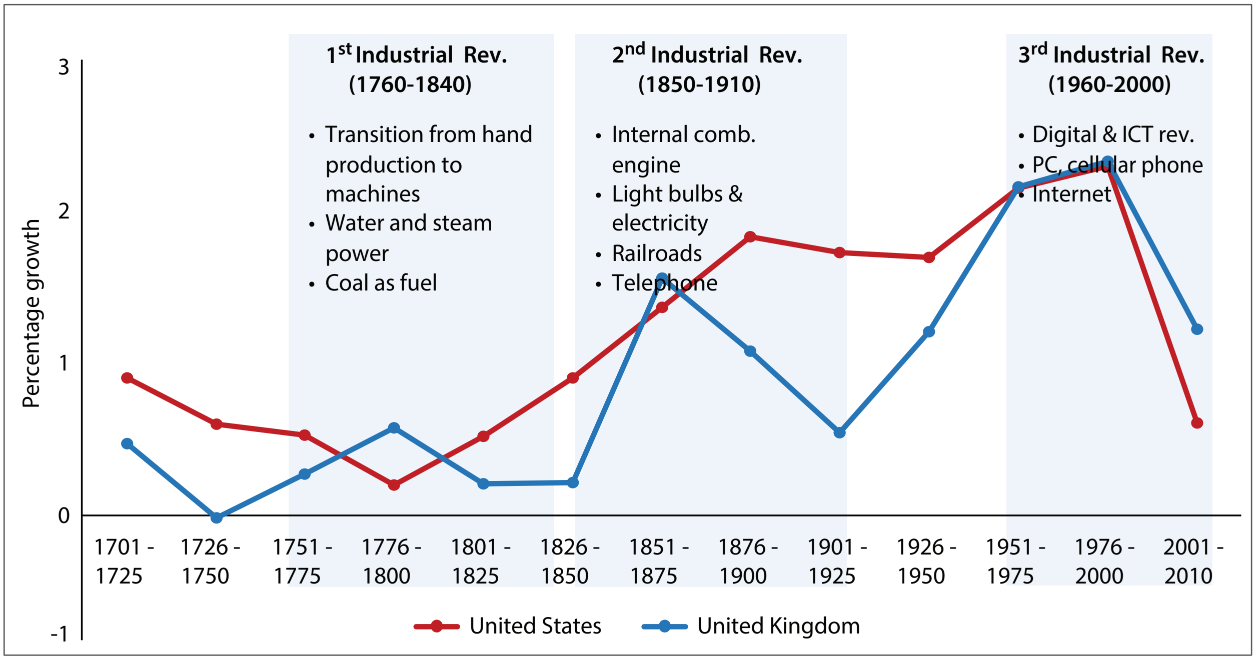
Given their significant impact on economic development, an examination of past industrial revolutions offers broad insights into what a future revolution may bring. Figure 3.1 illustrates some important features of these past technological revolutions. It shows the changes in living standards since the 1700s, as measured by GDP per capita growth, in the United Kingdom and the United States, which were the leading countries of the first and second industrial revolutions, respectively.

6 The Luddites were a group of textile workers in 19th century England, who protested against the increasing use of automated looms and knitting frames, arguing that it robbed them of their livelihoods.

7 Section 5 provides a detailed discussion of the competing views on the consequences of continued rapid technological progress.

Figure 3.1

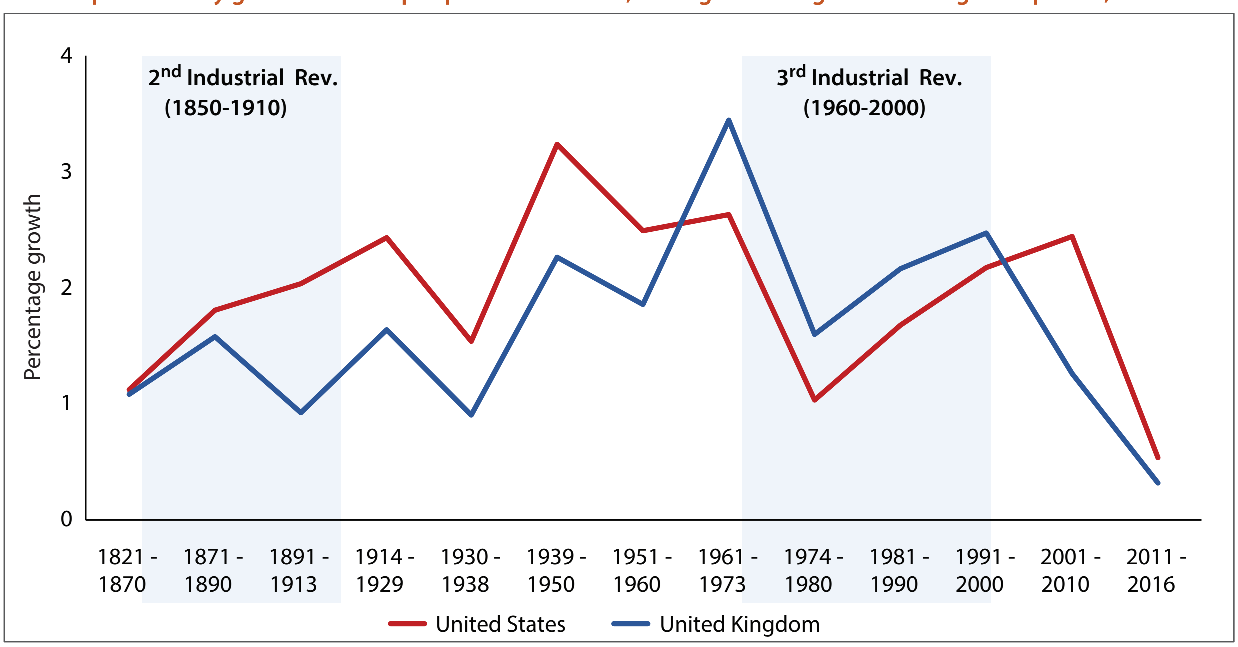
GDP per capita growth in the United Kingdom and the United States, PPP basis, annual average in each period 1701-2010



Source: UN/DESA estimates, based on Maddison Project.

Figure 3.2

Labour productivity growth and output per hour worked, average annual growth during each period, 1821-2016



Source: UN/DESA, based on the Maddison Project and The Conference Board Total Economy Database (May 2017).

As illustrated in figures 3.1 and 3.2 above, the full economic impact of industrial revolutions has only become apparent several decades after the initial technological breakthroughs. Technological revolutions take a long time to unfold and it is difficult to identify when they begin or end, even retrospectively. For example, productivity growth during the second industrial revolution rose rather slowly and was actually higher after the revolution than during it. Given these large time lags, it is difficult to ascertain in real time whether a technological revolution is currently taking place.

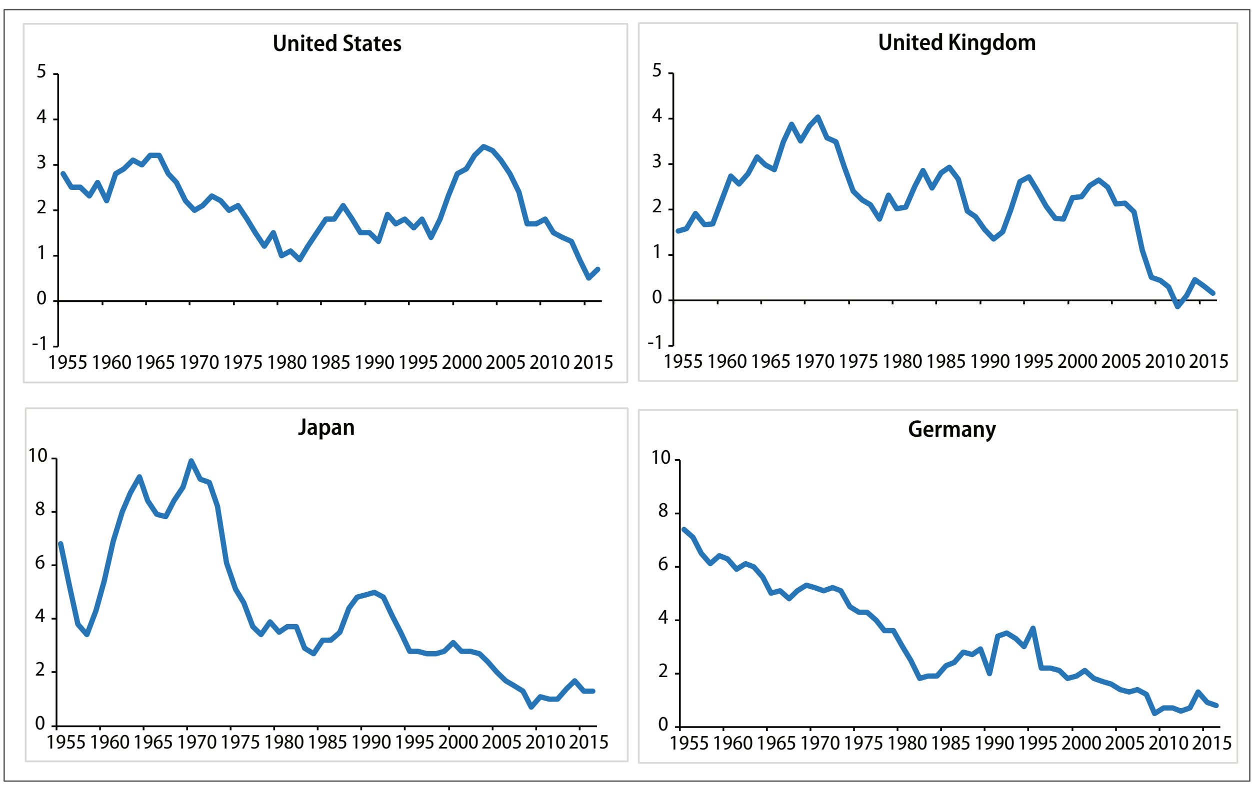
A common explanation for small productivity gains during the second industrial revolution is that even within the affected country, technological diffusion was slow (Atkeson and Kehoe 2001; David and Wright 2006). Similarly, productivity growth during the first industrial revolution in England was also slow, possibly because technological advances were concentrated in a few manufacturing sectors that were not large enough to have a sizable impact on total manufacturing and on the entire economy until the mid-19th century (Antras and Voth 2003). This implies that breakthrough technological inventions alone are not sufficient for a revolution and that diffusion is critical.

Since the 1960s, labour productivity growth in developed countries has been on a downward trend, briefly interrupted by the positive contributions often associated with the digital and information technology revolution. In the aftermath of the global financial crisis of 2008/09, productivity growth further declined notably, with GDP per person employed barely growing in recent years. This persistent weakness in productivity growth, illustrated in figure 3.3, has continued despite rapid advances in technology. As a result, there has been much discussion over the

Figure 3.3

Trends in labour productivity for selected developed countries, 1955-2016

Five-year moving average, percentage



Source: UN/DESA, based on The Conference Board Total Economy Database (2017) and Penn World Table 9.0 (Feenstra, Inklaar, and Timmer 2015).

role of technology in this so-called “productivity paradox” (see section 5.D).

As figure 3.4 shows, productivity growth in East and South Asia has been on an upward trend from 1975 onwards. This can be attributed to the transition from agrarian to industry-based economies in many countries of the region, such as China and the Republic of Korea. In the 2000s, productivity growth rose above 6 per cent in East Asia and 4 per cent in South Asia, in line with continued structural transformation and associated investments in technologically advanced sectors and related infrastructure.

In contrast, productivity growth in the other developing regions has been relatively subdued in recent periods. In Latin America, average labour productivity growth has been on a downward trend between the 1960s and the mid-1980s and has remained weak since. A similar trend has been observed in Western Asia and Sub-Saharan Africa. This implies that many of the natural resource dependent countries in these regions have been unable to promote structural change towards higher and rising productivity. The volatility in productivity growth also indicates that even over the medium-term, productivity is affected by commodity price movements and exogenous shocks such as the 2008-2009 financial crisis.

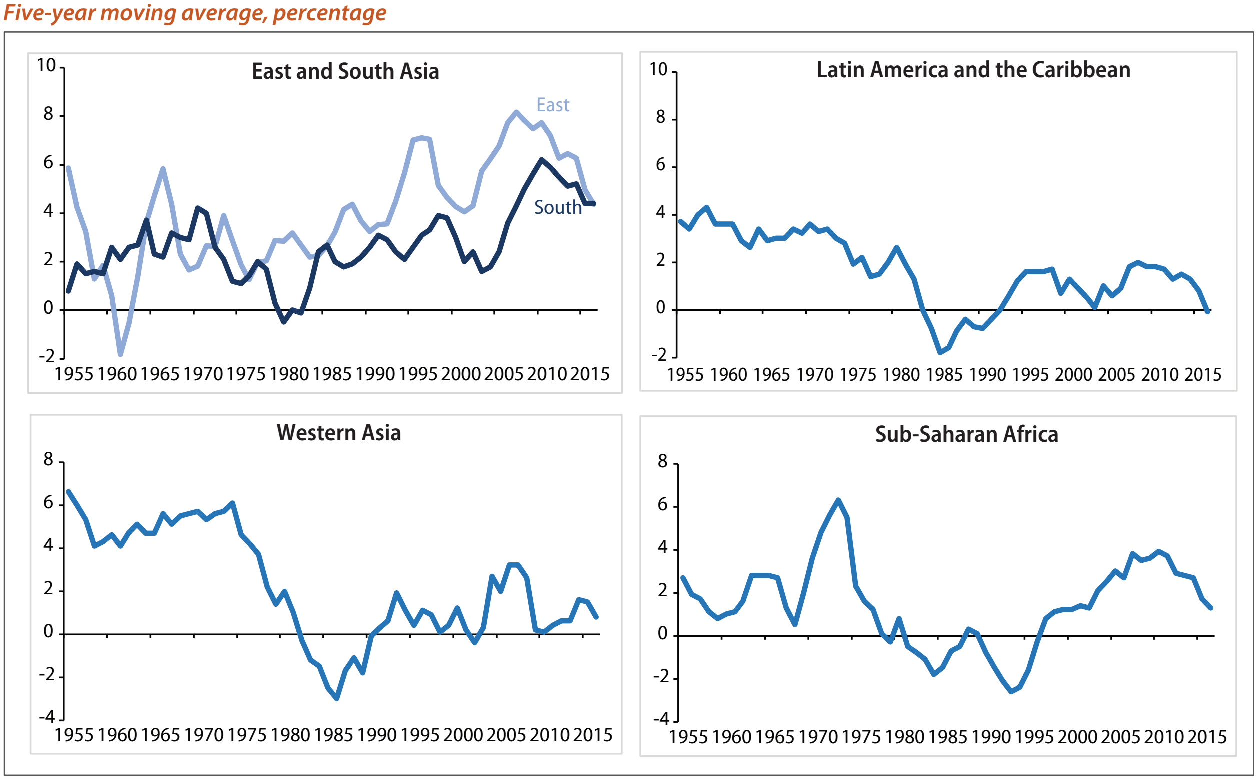
B. Sectoral employment shifts and work conditions

Between 1820 and 1913, over the course of the first two industrial revolutions, the share of the United States labour force employed in the agricultural sector shrank from 70 per cent to 27.5 per cent and currently stands at less than 2 per cent. This shift away from employment in the agricultural sector has been most pronounced in developed economies. However, many developing countries have also

Figure 3.4

Trends in labour productivity for selected developing and emerging regions, 1955-2016

Five-year moving average, percentage



Source: UN/DESA, based on The Conference Board Total Economy Database (2017) and Penn World Table 9.0 (Feenstra, Inklaar, and Timmer 2015).

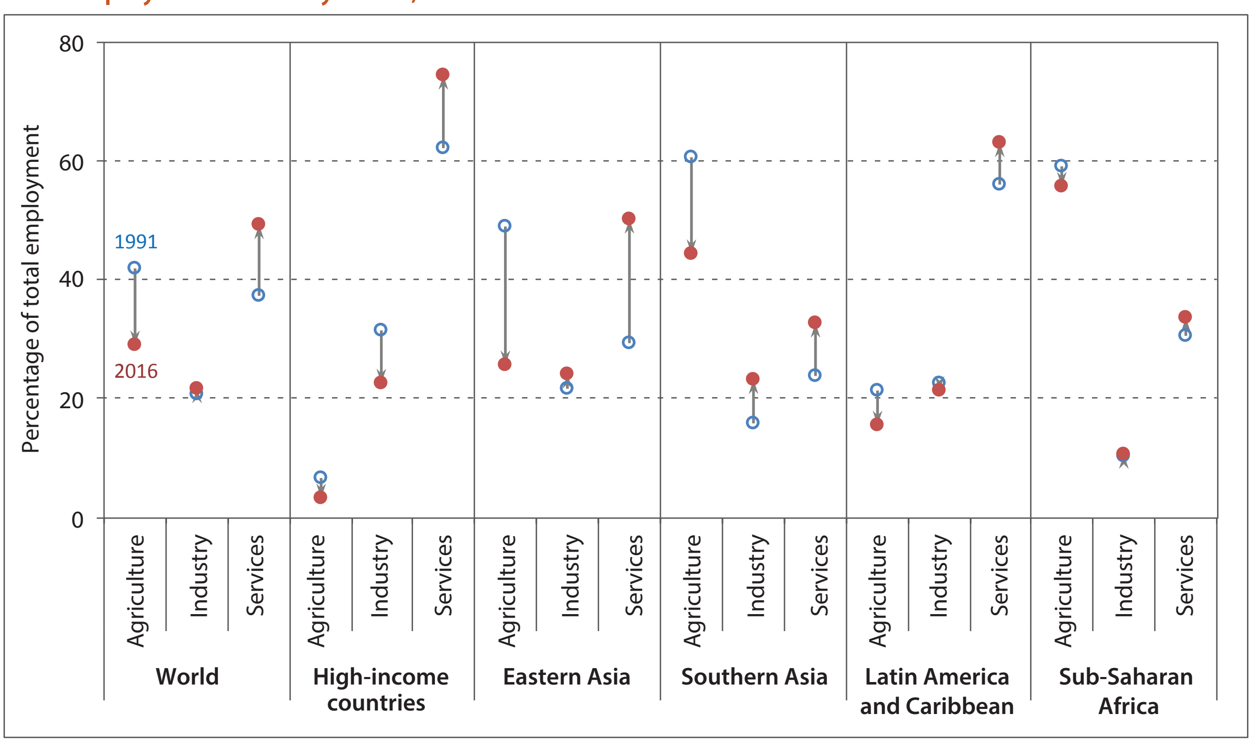
started to undergo a similar, and often even faster, structural transformation. Based on figures from the International Labour Organization, the share of agricultural employment in China fell from 80.8 per cent in 1970 to 28.3 per cent in 2015. In Latin America, the shift from agriculture to industry occurred much earlier, driven in part by import substitution policies. However, in most least developed countries (particularly in Sub-Saharan Africa), the agriculture sector still employs a majority of the population. In 2016, agriculture accounted for 69 per cent of total employment in this group of countries, a slight increase compared to 1991. This is indicative of a low level of technological absorption and has led some authors to argue that Sub-Saharan Africa is locked in a "technology trap" (Fofack 2008).

The gradually diminishing role of agriculture in employment over the past few decades has coincided with a greater mechanization of agriculture and the growing importance of the service sector. This trend has been reinforced by rapid digitalization and advances in information technology. Figure 3.5 depicts the shift in sectoral employment between 1991 and 2016 at the world level and for different groups of countries.

During that period, the share of agriculture in total global employment declined by 13 percentage points—an immense shift for a 25-year period. In contrast, the service sector share increased by about the same amount, reaching almost 50 per cent of total global employment. Meanwhile, the industry share has remained essentially unchanged at 21 per cent.

From a regional perspective, several trends are worth noting. First, the shift in employment from the agricultural to the service sector occurred in all major

Figure 3.5
Total employment shares by sector, 1991 and 2016



Source: UN/DESA, based on data from ILOSTAT (2017).
Note: Regional averages are based on all countries in the region, including low-, middle- and high-income economies.
Blue (empty) = 1991 and red (full) = 2016 values.

regions, albeit at varying degrees, with Asia experiencing the most significant sectoral transformation. Second, trends in industrial employment have diverged. While Eastern and Southern Asia saw a rise in the share of employment in industry, high-income countries have undergone substantial employment "deindustrialization".[8] Deindustrialization is also visible in Latin America and the Caribbean while the evidence for Sub-Saharan Africa is of a persistent lack of industrialization. There is significant heterogeneity within each region, however. The consequences of this process—which has been described as "Premature Deindustrialization" (Rodrik 2016)—are far-reaching. In many countries, economy-wide productivity growth has already suffered from the lack of the type of industries that promote economic development, despite good governance and policies.[9] This could impede economic catch-up and convergence going forward.

Across countries and regions, the service sector has in general exhibited the most dynamism, encompassing a diverse range of jobs. While highly skill-intensive service jobs such as ICT, computer systems design, finance and other business services have generally been on an increasing trend, their share in overall employment remains low, particularly in developing countries. A large part of employment growth in services has been in low-skill jobs, such as retail, travel or transport.

The ICT revolution and the shift from industry to services have coincided with profound changes to the nature of employment and working conditions, particularly in developed economies. Growing access to high-speed Internet has transformed how work is

Box 3.1

Technology and the participation of women in the labour force

In today's developed countries, female labour force participation (FLFP) rose significantly following the second industrial revolution, when demand for factory, office, and clerical workers increased rapidly (Goldin 2006). As explained by Galor (2005), capital accumulation and technological progress boosted women's real wages, inducing a rise in the FLFP rate. Moreover, since household technological change was one factor associated with increased school attendance for young women, it led to a rise in female employment among the next generation(s) (Lewis 2013). The greater use of computers during the recent digital revolution has further shifted job requirements towards more cognitive attributes, de-emphasizing physical skills.

For the United States of America, Goldin (2006) estimates that FLFP had declined for a century to reach a minimum point sometime in the beginning of the 20th century and rose steadily thereafter. FLFP was less than 20 per cent in 1890 and in 1940 it reached 40 percent. The rate peaked in 2000 at close to 80 per cent. Similar—but much less pronounced—historical trends were evident in other developed countries, including Australia, Belgium, Ireland, Italy, the Netherlands, Portugal, Spain and Sweden.

The gender participation gap has continued to narrow, but nowhere has this gender gap been eliminated, despite considerable regional variation (ILO 2017). In addition to uneven labour force participation, significant pay gaps, occupational segregation and unequal working conditions persist. Women are overrepresented in sectors that are characterized by low status and pay (ILO 2017). For example, the additional opportunities for women that resulted from globalization have often been in the form of "the lowest paid jobs, in piece-rate, subcontracted work, and insecure forms of self-employment, with little or no access to decent work and social protection" (United Nations 2017).

8 In several high-income countries, including the United States and the United Kingdom, the manufacturing industry's share of employment has fallen to only about 10 per cent.

9 One example of these so-called "escalator industries" is formal manufacturing.

structured, given enhanced access to information, improved connectivity and increased efficiency of business processes. This has allowed for greater job flexibility for both workers and employers. Based on data from the Bureau of Labor Statistics, in the United States, the percentage of wage and salary workers with flexible work schedules increased from 13.6 per cent in 1985 to 29.6 per cent in 2004. Widespread digitalization has also facilitated work-from-home arrangements. Meanwhile, technology has also enabled more fragmentation of business models, including through hiring contingent workers that work on demand for a defined period of time, such as freelancers (Valsamis 2016). In the United States, 15.8 per cent of workers were either on-call workers, contract workers, independent contractors or freelancers in 2015, whereas the figure was 10.7 per cent in 2005 (Katz and Krueger 2016).

Overall, the shift towards more short-term, flexible job structures has contributed to an increasing prevalence of precarious employment conditions in developed economies. According to a recent study by the European Parliament (2016), the share of standard contracts, which carry a low risk of precariousness, has fallen in the European Union over the past decade. Part-time work (often involuntary) and other forms of non-standard employment have instead been on the rise.[10] The ongoing shift towards non-standard forms of employment is associated with reduced worker benefits and welfare protection, with potentially significant economic and social implications.

The gradual decline in manufacturing employment that followed from globalization and automation, has been a contributing factor in the decline in trade union membership rates over the past few decades. In OECD countries, trade union density fell from 34.1 per cent in 1980 to 16.7 per cent in 2014. Since 1999, the decline for the group as a whole was of 4.3 percentage points (figure 3.6), with significant variations across countries.

C. Income inequality

The first and second industrial revolutions spurred strong growth in income levels in the frontier economies, including the United States and Western Europe, relative to the rest of the world. This contributed to the consistent widening of global inequality[11] from the 1820s up to the 1990s (Bourguignon and Morrisson 2002), as shown in figure 3.7. Milanovic (2016) noted that global inequality levels saw some stabilization in the 1980s and began a sharp decline in 2003. This trend can be largely attributed to rapid growth in income levels in China and India. These economies benefitted from domestic policy shifts as well as rapid technological progress, amid a rise in globalization and the proliferation of global value chains (GVCs).

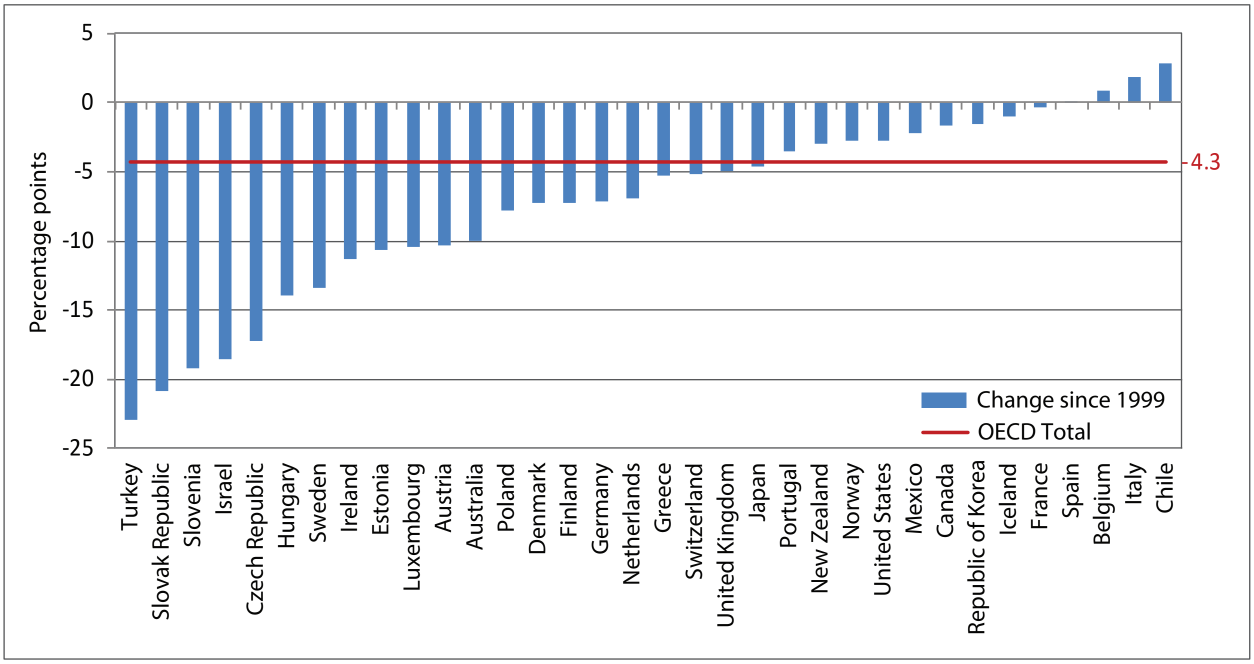
Inequality within countries has exhibited heterogeneous trends, across regions and time periods. As illustrated in figure 3.8, within-country inequality tended to increase in most major regions during the 1980s and early 1990s. This trend persisted in developed countries, driven in particular by rising inequality in the United States. Countries in Latin America and the Caribbean and Sub-Saharan Africa—with some of the world's highest income inequality levels—have begun to see some improvement in income distribution since the mid- to late 1990s. Since the early 2000s, within-country inequality has also stabilized or even improved modestly in other developing regions. However, it remains to be seen whether these developments will last. In particular, the global financial crisis—with its uneven impact on different households—has complicated

10 It should be noted that open-ended full-time contracts are still the main type of working relationship in Europe, currently accounting for about 59 per cent of all employment.

11 Milanovic (2016) defines global inequality as the summation of two components. The first is the weighted sum of the differences in mean incomes among nations, or the "location" component. The second is the weighted sum of the inequalities of personal incomes within nations, or the "class" component.

Figure 3.6

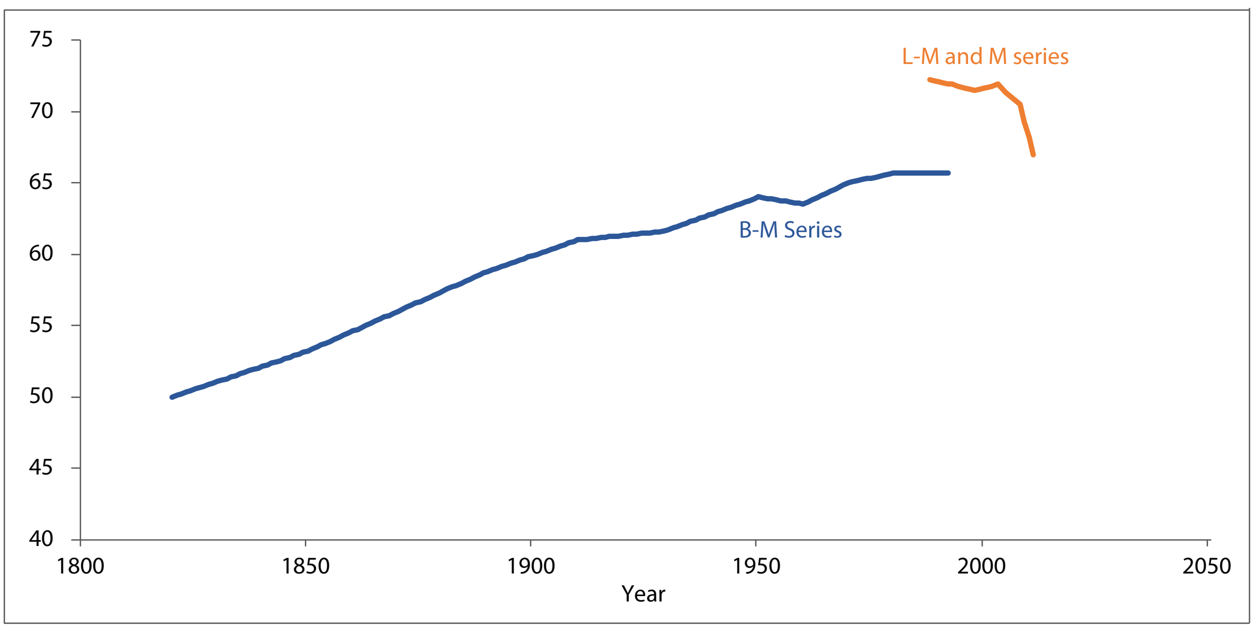
Change in trade union density in OECD countries from 1999 to latest available year



Source: UN/DESA, based on data from OECD.Stat "Trade Union Density" series.
Note: 1999 is the first year in which data are available for all of the countries in this sample. Latest available data are from 2012, 2013 or 2014.

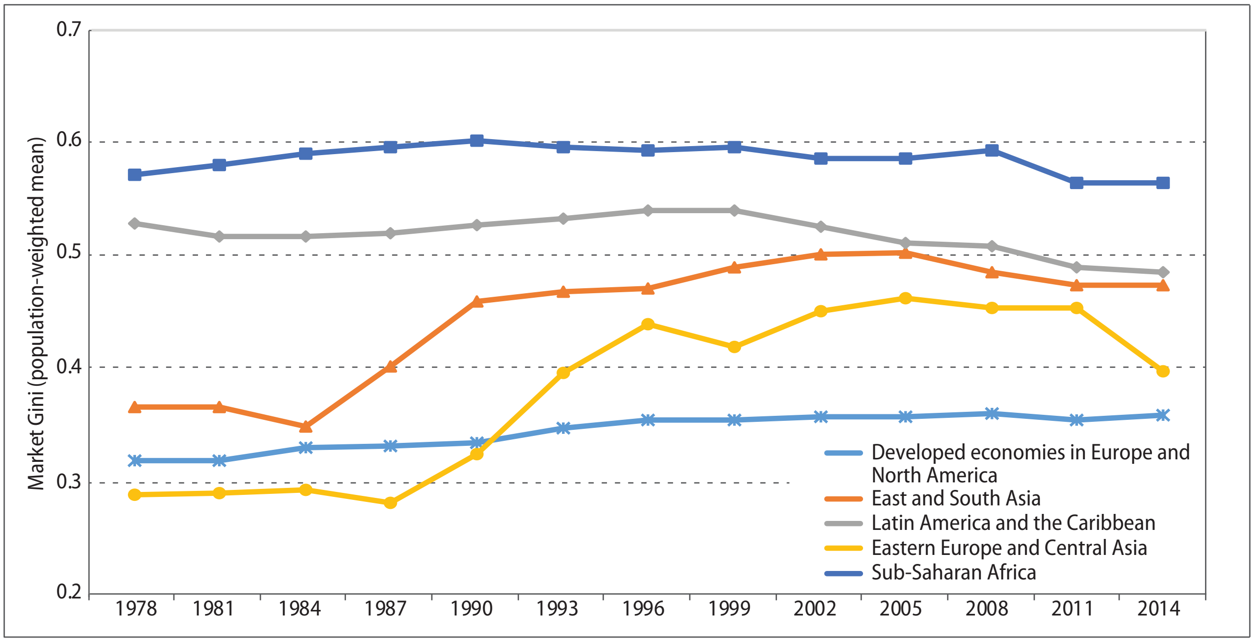
Figure 3.7

Global GINI coefficient, 1820-2011



Source: UN/DESA, based on B-M data from Bourguignon and Morrisson (2002), L-M data from Lakner and Milanovic (2013) and M data from Milanovic (2016).

Figure 3.8
Evolution of income inequality, by selected region, 1978-2014



Source: UN/DESA, based on data from Global Consumption and Income Project.
Note: The data shown here start in 1978 and end in 2014, with two years between each observation.

the narrative regarding the long-term trajectory of income distribution.[12]

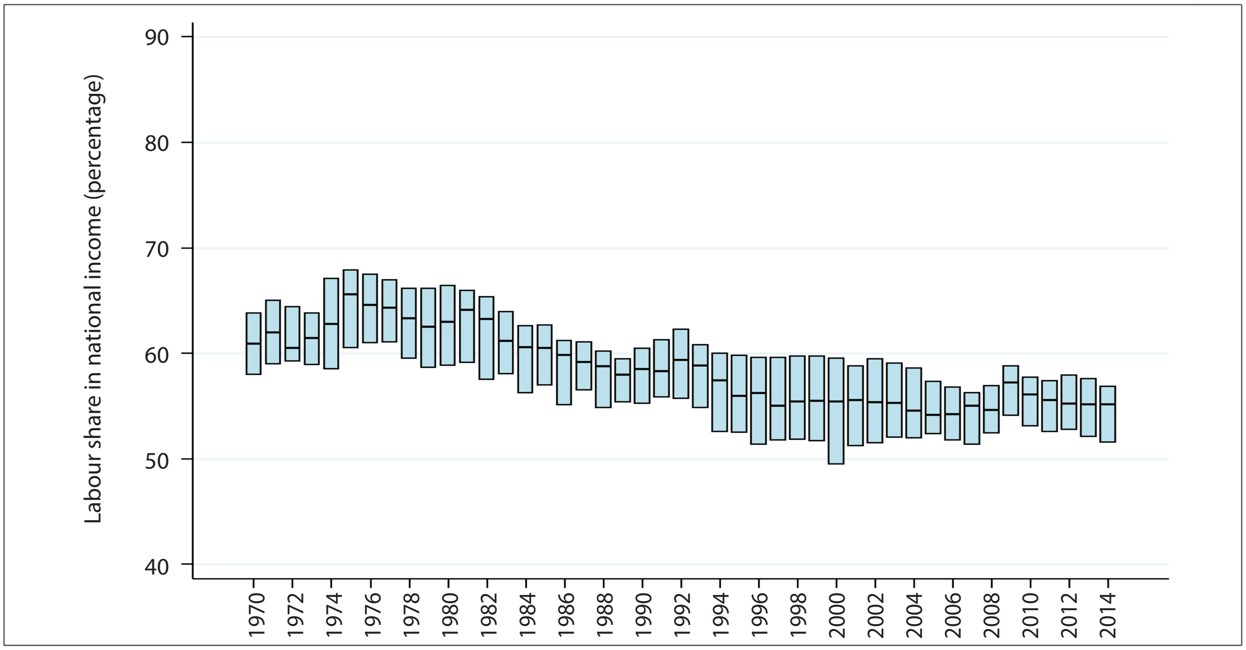
While being an important determinant, labour income inequality cannot fully account for the evolution of income inequality over the years. Income inequality is also influenced by the distribution of income between labour and capital, which again is affected by technological changes.[13] The recent focus on functional income distribution is partly motivated by the observation of a broadly declining labour share in national income in many developed countries since the mid-1970s, and in some developing countries since the 1990s (Karabarbounis and Neiman 2014). As labour income accounts for a larger share of income for households at the bottom of the distribution than for those at the top, and capital is typically more unevenly distributed across capital owners, a fall in the labour share in national income is associated with a worsening income distribution.[14]

12 For example, during the global financial crisis, high-income households often saw a relatively larger drop in income than lower-income households (ILO 2015a).

13 The IMF, to name just one recent example, finds evidence that technological progress results in a decline in the labour income share as it is replaced by capital (IMF 2017).

14 Some recent studies have, however, cast doubt on the narrative of a significant global decline in the labour income share (Bridgman 2014; Cho et al. 2017). Accounting for capital depreciation and adjusting for self-employment, the authors find little or no decline in the labour income share over the past decades. Rognlie (2015) highlights the role of housing capital income in explaining falling labour shares.

Figure 3.9
Trends of labour income share, for 19 selected developed countries, 1970-2014



Source: UN/DESA, based on data from ILOSTAT.
Note: The line in each box indicates the median country value for each year, with the top of the box denoting the third quartile and the bottom denoting the first quartile.

4 How does technological innovation affect labour markets and inequality?

What role has technology played in shaping past employment and inequality trends? It is difficult to separate the effects of technology from those of other structural shifts, such as changes in institutional systems and social norms, the globalization of production and markets, labour, education and tax policies. While technological progress has contributed to job destruction over the past two centuries, new technology has also helped to create jobs, many of which are in new sectors and industries.[15] Amid the evolving skillsets demanded by the labour market, technological progress has had wide-ranging distributional effects, producing both winners and losers. This section examines the various channels through which technological innovations tend to affect employment and income inequality, drawing on theoretical arguments and recent empirical evidence.

A. Job destruction and job creation

The main objective of introducing new workplace technology is to increase productivity. This is often achieved by substituting capital for labour, with new machines performing tasks that were previously carried out by humans. The tractor, the combine harvester, the forklift and desktop publishing software are prominent examples of labour-saving technologies. In general, new technologies substitute workers only in specific tasks, but do not necessarily eliminate entire occupations, for instance farm workers, warehousemen and typesetters. According to a recent study by Bessen (2016), only one out of the 270 occupations listed in the 1950 US Census had been eliminated by 2010 due to automation: the elevator operator.

15 In the United States, for example, about 7 million private sector jobs were lost in the third quarter of 2016, while 7.7 million jobs were created.

Rather than eliminating occupations, technology changes how jobs are performed and the number of humans needed to carry them out. Through the introduction of new tools and techniques, technological progress at times alters the tasks an occupation requires. The role of bookkeepers, for example, has been rapidly changing with the use of computers and specialized software. Instead of mainly tracking and recording financial transactions, they increasingly serve as data managers and advisors for clients. Bessen (2016) has therefore characterized the automation witnessed over the past half century as 'partial automation'. Often the result is a reduction in the number of jobs in an occupation, as was the case for telephonists and telegraph operators in England and Wales (Stewart et al. 2015).

Recent empirical studies have classified tasks along two dimensions: "manual" versus "cognitive" (abstract) and "routine" versus "non-routine" (see, for example, Acemoglu and Autor 2011 and Cortes, Jaimovich and Siu 2016). Routine tasks are tasks that are based on well-understood procedures and can be described by clear rules and algorithms (Autor, Levy and Murnane 2003). Non-routine tasks, by contrast, require flexibility, creativity, complex problem-solving or human interaction.[16] Technological advances in the past few decades—in particular the rapid gain in computer processing speed and power—have primarily led to the automation of routine tasks. This has contributed to a long-term decline in occupations that mainly involve routine activities, both manual and cognitive.[17]

The job-destroying effects of new workplace technology are counterbalanced by job creation effects. There are several channels through which technology helps create jobs. First, automation complements specific job tasks. This makes workers who perform these tasks more productive and more valuable, potentially boosting demand for such labour. In recent decades, this effect has been reflected in the increased demand for workers that perform non-routine, cognitive tasks, particularly in knowledge-intensive industries. According to Stewart et al. (2015), management consultants, business analysts and information technology managers have been among the fastest-growing occupations in England and Wales since the early 1990s. Second, technological innovations propel new industries and help develop new products, often meeting previously unfulfilled human needs and generating additional employment. Third, technological innovation and automation positively impact productivity, driving down costs and prices. This is likely to raise demand, thus increasing production and employment.[18] Fourth, productivity gains lead to an overall increase in economic growth and income, thus creating higher demand for both new and existing products and services. For example, rising incomes have boosted expenditures on activities related to leisure, such as travel or dining, and on health care, generating more jobs in these industries. Many of the occupations that have seen particularly strong job growth in recent decades are non-tradeable service occupations that are not automatable—at least for now.

Table 4.1
Job destruction and creation

Job Destruction	Job Creation
Reduces labour required to perform tasks	Automation complements specific job tasks
Automation of tasks; some occupations eliminated	Creation of new industries and products
Technology alters the tasks an occupation requires	Increase in productivity, lowers costs and prices
	Higher growth and income, thus boosting demand

Source: Author compilation.

16 Routine manual activities are performed by machine operators, dressmakers and meat processing workers, among others. Routine cognitive activities are performed by bookkeepers, travel agents and mail clerks, among others.

17 Autor (2015) shows that in the United States, physically demanding, repetitive work has receded steadily since the 1940s. Routine cognitive work, by contrast, expanded rapidly until the 1970s, before reversing course and shrinking in the past few decades.

18 A famous historic example of this productivity effect is the automation in the 19th century weaving industry (Bessen 2015). Although 98 per cent of the labour required to weave a unit of cloth was automated, the total number of weaving jobs increased as lower prices resulted in a rapid increase in the highly elastic demand for textiles.

How have job destruction and job creation played out over time?

By and large, technological anxiety and fears of mass unemployment have proven unfounded. As far back as the late 19th century, economists noted that employment grew the most in the industries that made increasing use of machines (Mokyr et al. 2015). Recent empirical evidence for England and Wales indicates that over the past 150 years, technological progress has created more jobs than it has destroyed (Stewart et al. 2015). Phases in which technology-related job destruction dominated were always followed by periods of large-scale job creation.[19] Employment-to-population ratios generally increased during the 20th century, with women entering labour markets on a large scale, particularly in developed countries.

In the long run, technological progress has reinforced—rather than weakened—the overall need for human labour. However, the disruptive effects of new technologies should not be ignored. While technology-induced job losses are immediate, the creation of new jobs often takes time. In addition, the new jobs frequently differ from the old ones in terms of industry, required skills and geographical location. This not only increases the risk of

Box 4.1

A history of concerns regarding rapid technological progress

The anxiety brought about by technological progress is not a new phenomenon. In ancient literature, the myth of Prometheus is perhaps the earliest example. Headlines from the past two centuries illustrate the continuous fear of technological unemployment.

Economists have debated the impact of technological progress on labour and inequality since as far back as the first industrial revolution. The three most prominent concerns identified by economists are the potential of technology to replace workers on a large scale ("technological unemployment"); the routine mechanization and dehumanization of work; and the fear that productivity growth will not be sufficient to counteract other economic headwinds.

As illustrated by the historical analysis in Mokyr et al. (2015), there has been broad agreement on the long-run productivity gains from technological progress and on the labour-replacing effects of mechanization. A much larger debate has existed on how to balance these two effects.

To justify the short-term effects, some have argued that long-run effects would boost total demand for labour (David Ricardo) or that disruptions are temporary while productivity gains are permanent and widespread (Sir James Steuart). Others have argued that production gains are always beneficial to workers as a group, even in the short run (John Stuart Mill) or that technological improvement is a path to greater prosperity even if short-term effects lead to the capitalist-driven immiseration of workers (Karl Marx).

The empirical record of the effect of the industrial revolution in the 19th century on the British economy supports the view that technological progress results in greater overall employment (see section 4.A). Rather than widespread unemployment, the problem was the low quality of work in the new factories, which led to long hours, poor job security, poor air quality in and around factories, and other concerns.

It is also true that the distress caused by new machines and production methods was real for individuals and groups, even if the overall demand for labour continued to increase. Industries that relied on artisanal methods could not compete with the rapid mechanisation and were wiped out. The gap between factory workers' wages and those of artisans increased, "hollowing out" the skill distribution in manufacturing.

Source: Mokyr, J., C. Vickers, and N.L. Ziebarth (2015), "The History of Technological Anxiety and the Future of Economic Growth: Is This Time Different?" Journal of Economic Perspectives 29, 31–50.

19 The sectoral shifts described in section 2 illustrate how technological progress can have wide-scale effects on an entire sector (agriculture) and result in increases in productivity and total employment as resources shift to other sectors.

displacement for workers, but also poses challenges for policymakers (see section 6).

Instead of resulting in an aggregate loss of jobs and widespread unemployment, technological innovations can contribute to higher levels of underemployment in the form of part-time employment or over-qualified workers. There is some evidence that, in the United States, recent technological progress has contributed to underemployment in certain industries, especially the food service sector. While open unemployment is low in many developing countries, underemployment is pervasive and can partly be attributed to the adoption of labour-saving technologies (Pritchett 2017).

B. Occupational shifts, job polarization and wage inequality

The spread of new technologies over the past few decades has contributed to profound changes in occupational structures and significant redistribution, both between capital and labour and between different types of workers. While these trends vary by country, there are some commonalities, particularly among developed countries. As described previously, automation in recent decades has mostly substituted for routine manual and cognitive tasks. Many of the jobs that are routine-task-intensive are in the middle-wage category (e.g. manufacturing and routine office workers). Jobs that are non-routine-intensive, on the other hand, can often be found at opposite ends of the wage spectrum: managerial, professional and technical specialists at the top and service sector workers, such as manicurists, bartenders and personal workers at the bottom.

The combination of routine-biased technological change and offshoring has led to job polarization across developed economies. Since the 1980s, employment has shifted away from middle-wage jobs towards both high-wage jobs and low-wage jobs. This "hollowing out" of the middle of the wage distribution has been extensively documented for the United States (see, e.g. Autor, Katz and Kearney (2006) and Acemoglu and Autor (2011)) and for European countries (Goos, Manning and Salomons 2014).[20] For example, in a sample of 16 European countries for the period 1993-2010, the average employment share of middle-paying occupations declined from 47 per cent to 38 per cent.[21] Recent work by the World Bank (2016) indicates that labour markets have also become more polarized in many developing countries since the mid-1990s, with the share of middle-skilled occupations declining. There are, however, some notable exceptions to this trend, including China and Ethiopia, where this hollowing out is not observed.

In some cases, this job polarization has been accompanied by rising wage inequality. Since 1970, the real wages of high-skilled workers have not only risen faster than those of medium-skilled workers whose jobs are declining, but also faster than those of low-skilled workers. This trend is particularly evident in developed countries, most notably the United States. In the majority of developed countries, wage inequality (measured by the 90:10 ratio[22]) is higher today than 40 years ago, with the bulk of the increase occurring in the 1980s and 1990s. In the United States, where wage inequality is significantly higher than in any other developed economy, the 90:10 ratio rose from 3.65 in 1979 to 5.05 in 2016, mainly due to increased inequality at the top of the distribution.[23] While wage inequality has also increased in Australia, Canada, Germany and the Nordic countries

20 According to Barany and Siegel (2015), modern polarization in the US labour market started as early as the 1950s.

21 A further breakdown of the middle-wage job category reveals a shift from more traditional sectors such as production, clerical work and construction towards newer sectors, including health care and lower management (Holzer 2015).

22 The 90:10 ratio is defined as the ratio between the gross wages of individuals at the 90th percentile of the wage distribution (90 per cent of full-time workers have lower wages) and the 10th percentile (10 per cent of full-time workers have lower wages). It should be noted that this indicator does not capture one of the most important recent trends in wage inequality, namely the strong redistribution to those in the top 1 per cent.

23 In most developed countries, rising wage inequality has been driven mainly by the widening gap between top 10th percentile wages and median wages rather than that between the median wages and the bottom 10th percentile wages.

since the 1980s, it has remained constant or declined in some other developed countries, such as France, Italy and Japan. Among developing regions, there have been varying trends in wage inequality over the past few decades. In Latin America, the 90:10 ratio increased from the early 1980s until the late 1990s, but has declined since then. By contrast, many East Asian countries, including Indonesia, Republic of Korea, the Philippines and Viet Nam, have seen a relatively steady increase in wage inequality since the 1990s.

The rise in wage inequality can be partly attributed to the strong complementarities between information technology and cognitive activities, which have increased the marginal productivity of high-skilled workers. In some cases, this effect has been compounded by institutional factors, such as the fall in unionization and the fact that the labour supply of low-skilled workers is more elastic than that of high-skilled workers.[24]

C. Technology and globalization

Globalization, i.e. the massive increase in cross-border trade and financial flows as well as, to a much lesser extent, in migration, is often seen as the main driver of trends in labour markets and inequality in both developed and developing countries.[25] The global shift of manufacturing towards developing economies in Asia has also been a factor for the emergence of the middle class in many Asian developing countries, as it allowed for the movement of workers from agriculture to better paying jobs in manufacturing. Technological change and globalization are not independent of each other and are indeed closely related. Technological advances in logistics (in particular the introduction of the container[26]), communications and finance played a major role in reducing costs and time of cross-border transactions, thereby facilitating globalization. At the same time, deeper regional and global economic integration has expanded firms' access to foreign markets. This provides incentive for firms to further invest in the development of new technologies, including in the areas of logistics, communication and finance in order to fully harness the potential of new consumer market opportunities. However, technology is not the only factor behind globalization. Political choices such as the reduction in tariffs and capital controls as well as major shifts in China's economic policies have also been critical.

In the current phase of globalization, a large part of trade is due to offshoring and outsourcing that enables the emergence of GVCs, in which different steps of the production process are undertaken by different firms in different parts of the world. While only a limited number of firms are participating in GVCs, these firms typically have a higher productivity than non-exporting firms. The link between technology, productivity differences across firms and trade can be explained by new trade theories[27] that show how the decision to export is connected to fixed cost investments such as the adoption of technology. Within industries, exporting firms are more productive than non-exporters, in part due to greater incentives for these firms to adopt technology in their production process. The reverse is also true: companies that are more productive are more likely to participate in international trade. Greater revenues from exporting help to amortize the fixed costs in technology, and so both are mutually reinforcing. The result is a widening gap in the incomes of highly productive firms and those that cannot invest in technology. Automation increases competitive forces that are amplified by the GVC and, in order for countries to remain

24 The supply of skilled labour – measured as the number of college graduates – rose only slowly in the US in the 1980s and 1990s, but has increased markedly since then. In many European countries, skilled labour supply has increased more significantly over the past few decades, dampening the skill premium and wage inequality.

25 See Harrison et al. (2011) for an overview on how trade can contribute to within-country inequality. See, among others, Autor et al. (2013) for evidence for the United States and Helpman et al. (2017) for Brazil.

26 See Levinson (2008). A recent study estimates that maritime trade would decrease by one-third if container technology did not exist (Cosar and Demir 2017).

27 The so-called "new new trade theory" has been developed by Melitz (2003) and is based on the new trade theory developed by Krugman (1979).

competitive, their firms must adopt new advanced technologies in production. At the same time, the wave of offshore-outsourcing of manufacturing and business-related services from developed to developing and transition economies (which intensified especially in the early 1990s), greatly delayed the adoption of automation in advanced economies (which had rapidly increased in these countries in the 1980s). As labour costs in developing countries increased and the cost of automation technologies greatly decreased, the primary rationale for moving production to developing countries no longer applies in an increasing number of sectors and has reversed in some – the result may well be a phase of "reshoring" (see section 5.E).

GVCs provide opportunities for firms also in developing countries to integrate themselves into global markets, as it allows them to concentrate on areas commensurate to their capacities, rather than having to compete on complete and complex production processes. Thereby, GVCs have created jobs in developing countries, in many cases for women. However, GVCs are no panacea. Without technological upgrading, firms in developing countries capture only a small part of the value added and make only limited progress towards structural transformation. Countries that encourage investment in technology and automation and have the required complementary skills and infrastructure are better positioned to take advantage of GVCs. However, many poorer developing countries lack these skills and infrastructure. The ability of a country's exporting firms to innovate and remain competitive during periods of rapid technological change ultimately depends not only on the technologies available, but also on many other factors, including the size of the exporting sector, the skill level of the workers, the availability of finance, and the size of the export and domestic markets.

D. Technology and market structures

A key factor that simultaneously contributes to increasing inequality and the shrinking labour share of income is the change in market structure leading to increased monopolistic rents and high profits made by relatively few firms. As with globalization, technology can be one reason for increased market concentration. Many key industries in the current wave of technological progress, such as social media platforms and e-commerce platforms, are characterized by network effects due to demand-side economies of scale (David 1990). The larger the network gets, the more users (either new users or those from competing networks) it can attract, thereby further increasing the network size. In addition, technological innovations have facilitated a global marketplace that allows near-frictionless commerce, further increasing the benefit of being larger than rival firms. Moreover, if diffusion of key new technologies to other firms is limited (due to, for example, restrictive intellectual property regulations), the successful introduction of new products and processes in the markets can also increase market concentration. For these reasons, competition can often take a 'winner-takes-all' (or 'winner-takes-most') form, leading to the emergence of so-called 'superstar firms' that dominate markets and profits, which can explain patterns of the declining labour share of income across industries and countries (Autor et al. 2017).

While wages in such firms are typically higher than in the remaining competing firms, many of these firms employ a relatively large share of skilled labour, thereby contributing to wage inequality. In addition, the compensation of chief executives is typically also far higher in successful superstar firms, further increasing wage inequality. Moreover, as profits accrue to owners, the increasing share of profits relative to revenues contributes to a rising overall share of capital in income.

However, technology is certainly not the only factor explaining the upward trend in the profit share. For example, Guvenen and Kaplan (2017) demonstrate that, in the United States, the rise in income of the top 0.1 per cent is due to increasing capital income in so-called pass-through entities, a corporate form rarely used by technology firms. Hence, an increase in monopolistic rents is not simply a consequence of new technologies, but is also driven by regulatory policies and lobbying activities that limit market entry.

E. Technology and the organization of work

The current technological changes do not only impact the number of jobs and tasks workers will need to be able to perform, but also the overall organization of work. Particularly in developed countries, work becomes less firm-centric. Emerging large technology firms increasingly resemble platforms, which employ only a few workers themselves. Instead, work tasks are performed by individual contractors, who may work for a variety of firms at the same time. Cooperation and competition among firms has become a dominant work arrangement especially among smaller high-tech firms. On one hand, the shift away from traditional work arrangements to contingent work can increase flexibility and create gainful employment opportunities for people (often women) for whom standard full-time employment conflicts with family work or education. However, many non-standard work arrangements lead to precarious work relations, with workers having to bear employment and income risks by themselves. In turn, precarious work is negatively related to occupational health and safety (Quinlan et al. 2001, from NASEM et al. 2017, p. 85).

Contingent workers typically have weaker bargaining power compared to traditional workers, as they are more easily replaceable, except for those who perform highly specialized tasks. Moreover, the possibility of outsourcing tasks to contingent workers reduces the bargaining position of workers in traditional employment relations as well. In addition, non-traditional workers are typically not covered by labour union contracts, further reducing the bargaining power of labour compared to firm owners. With the unionization rate already shrinking for other reasons such as changes in labour laws and socio-demographic patterns, the changes in the organization of work can contribute to a lower labour share in income and higher income inequality.

Moreover, technology-induced changes in the organization of work can also have indirect effects on inequality by affecting the scope for redistribution. In many countries, social protection (such as health insurance, unemployment insurance, and pension benefits) is largely tied to traditional employment. Hence, unless social protection systems are reformed, an increase in contingent workers leads to reduced social protection coverage and hence less redistribution.

F. Technology and the informal sector

For developing countries, an important concern is the impact of technological progress on the informal sector, which dominates employment in many economies. Across developing countries, women and young people are more likely to be engaged in informal work.[28] The impact of technological change in the informal sector will largely depend on the rate of diffusion of new technologies in developing countries, particularly in rural areas, household-based enterprises and small scale producers and service providers, where informal employment is most prevalent. Informality could be affected in several ways as discussed below.

First, if technology adoption expands employment in manufacturing and more structured service provision, it will contribute to the reduction of informality. In this case, formal employment creation would foster the relocation of labour away from agriculture, thus reducing informality and precarious labour arrangements. Indeed, the past wave of technological development associated with the outsourcing of manufacturing activity from developed to developing countries led to important gains in formal wage and salaried employment (especially in manufacturing).[29] In fact, in developing countries the share of wage and salaried jobs in total employment grew from 49 per cent in 1995 to 65 per cent in 2015

28 The share of women in informal labour exceeds that of men by 4.9 percentage points in total, and by 8.7 percentage points if agriculture is excluded (ILO 2017).

29 In many instances, this benefitted women in particular.

– together with increasing shares of jobs associated to global supply chains (ILO 2015b).

A concern with the new wave of technological change, however, has been raised in relation to the impact of automation in production, (e.g. the use of robots and 3D printing among many other forms of automation). As discussed above, it may lead to the displacement of workers in formal occupations, thus, increasing the incidence of informality and precarious work arrangements. Furthermore, if new technology leads to significant reshoring of production, the return of manufacturing back to developed countries could lead to large job losses in the most productive (and formalized) sectors in developing countries and consequently to greater informality (see section 5.E for a full discussion).

Second, effective diffusion of productivity-enhancing technology in rural contexts, where informality in employment is most prevalent, would allow agricultural firms to scale-up production, thus supporting the formalization of employment in agriculture and in industrial and service sectors linked to agriculture.

Third, information and communication technologies can make an important contribution to expand the scale of production among household enterprises and small scale firms, leading to the creation of new businesses (Garcia-Murillo and Velez-Ospina 2017). Extensive use of ICT can contribute to the expansion of the formal sector and a consequent decline of the informal sector in both relative and absolute terms (La Porta and Shleifer 2014). Digitalization and other advances in technology have spurred further offshoring of production from developed to developing countries, notably in services, and hold the potential to bring more people into formal salaried employment.

Fourth, wider use of basic technologies, such as mobile phones, can help workers in rural areas and informal workers in garments and construction to gather relevant information on prices and market conditions and to keep contacts with clients, increasing their income potential and chances of formalization (Casey and Hughes 2016). New ICT and financial technologies can facilitate the process of formalization by making it easier for firms to pay taxes and register payments, thereby improving firms' chances to have access to credit.

However, an additional concern has been raised around the increasing use of digital platforms to hire individual services, including across borders (the so-called "gig economy"). As these platforms are often set up with the explicit purpose to circumvent existing regulation and taxation, new forms of informal employment might arise and grow fast, in both advanced and developing countries (ILO 2016). So far, however, the impact on employment quality seems to have been more limited, with less than 1 per cent of total employment accounting for this type of new employment form, even in those countries where such services are most widespread (Polaski 2017).

On balance, the current technological changes, when properly regulated and accompanied by appropriate public policies, have the potential to strengthen formal employment and lower entry barriers for currently informal workers and companies to formalize. However, there is a risk that policy inaction and lack of appropriate regulatory frameworks may result in greater fragmentation of labour markets and an increase in the incidence of informal employment arrangements.

G. Technology and female labour force participation

The relationship between technological advances, structural transformation and women's labour force characteristics is highly nonlinear and complex, varying widely from country to country. One mechanism linking technological progress with women's participation in the labour force is the rapid spread of labour-saving household electrical appliances. As noted in box 2.1, the spread of household labour-saving technologies was associated with increased school attendance (Lewis 2013). Indeed, educational attainment is one of the main determinants of women's labour force participation (Attanasio, Low and Sánchez-Marcos 2008). It also helped reduce women's reservation wage (i.e. the opportunity cost of entering the labour market), providing an incentive to enter the labour market (Goldin 2006).[30]

The interaction between technological progress and structural transformation also has important gender implications. The movement from subsistence agriculture into manufacturing and services is typically associated with increased use of capital-intensive agricultural technologies, which often are more complementary to male than female labour, providing one explanation for a decline in female labour force participation in the early phases of structural transformation (Olivetti 2014). However, work in light manufacturing such as electronics, which played a significant role in the structural transformation of Asian economies, often requires tasks in which women have a comparative advantage, leading to an increase in their labour force participation (Olivetti 2014). Tejani and Milberg (2016) document an increase in the female share of employment in manufacturing over the period 1985-2006. However, the general upward trend masks major inter-regional differences. While the female labour intensity in manufacturing employment rose steadily in Latin America and the Caribbean, it started to decline in Southeast Asia with rising incomes since the early 1990s.

The shift towards services, in turn, generally promotes female labour force participation as well, as they emphasize cognitive skills over physical skills. Moreover, the shift in the task compositions of women's occupations from primarily routine to non-routine has been thought to be driven by technological change. The resulting increased emphasis on analytical skills has reduced the gender pay gap (by increasing the wages of women relative to men) in some instances (for example, Black and Spitz-Oener 2010).

Nevertheless, it is important to highlight that women's labour force participation is also determined by many other factors, as demonstrated by the fact that participation rates vary widely across and within regions. Women's labour force participation rates are the lowest in Northern Africa, Western Asia and Southern Asia (at 30 per cent or lower). The rate was below 50 per cent in Southern Europe and was between 50 and 70 per cent in other regions (United Nations 2015). In South Asia, female labour force participation rates range from 25 per cent in Pakistan to 80 per cent in Nepal. These vast differences not only reflect the different levels of education attainment, structural transformation, urbanization and development, but also underscore the importance of informal institutions, such as cultural or social norms, in influencing women's participation in labour markets.

It is also important to recognize gendered expectations regarding the burden of unpaid household and care work. Women work more hours than men overall when both paid and unpaid work is taken into account (United Nations 2015). If the cost of child care represents a significant portion of a women's wages, she may forgo wages to avoid this cost (Attanasio, Low and Sánchez-Marcos 2008). The shift away from traditional work arrangements to flexible work arrangements as a result of technological change may provide an opportunity for women to reconcile their reproductive and productive responsibilities. Indeed, Goldin (2014) argues that gender equality in the labour market will not be reached without more temporal flexibility. Yet, to date, segmented work histories and shorter work hours have only served to preserve the gender gap in pay (Blau and Kahn 2016). And while an increasing number of countries have adopted legislation providing maternity and paternity benefits, these benefits rarely extend to sectors or categories of employment such as domestic workers and casual and temporary workers (United Nations 2015).

To the extent that these factors continue to constrain women's labour force participation and wages, women may be less well-positioned to reap the employment opportunities provided by the technological revolutions.

30 Examples of such labour-saving electrical appliances are the washing machine, refrigerator and vacuum cleaner.

5 Looking ahead: What will technology mean for labour and inequality?

The technological and economic trends described in the previous sections have led to a heated debate about the effects that emerging technologies like AI will have on jobs and inequality. Technologies are encroaching in areas where human abilities were once deemed indispensable, threatening to do for cognitive ability what machines did for muscle power. The rapid diffusion of increasingly capable technologies is already evident, having contributed to the decline of middle-skilled jobs and rising wage inequality in several developed countries.

This section looks ahead and summarizes the various perspectives of what emerging technologies may mean for labour markets, macroeconomic indicators, and the global economic system. It is important to look beyond current trends and delve into how economies adjust in periods of rapid technological progress. The future will not only be shaped by the disruptive effects of new technologies, but also by how they enable changes and new opportunities. If history remains a guide, the broad contours of the future impact of a new industrial revolution indicate aggregate increases in employment. Work may become more flexible, but also more precarious for certain segments of the population.

A. The future of technological progress

The future of technological progress is one where the nature of work will change, some professions will disappear, some will grow, and new ones will be created. However, these long-term dynamics will be coupled with significant negative short-term effects for those that lose their jobs and find it difficult to re-enter the labour market. The impact of new technologies on labour markets is, however, not predetermined, but will depend on policies at the national and international levels, as discussed in section 6.

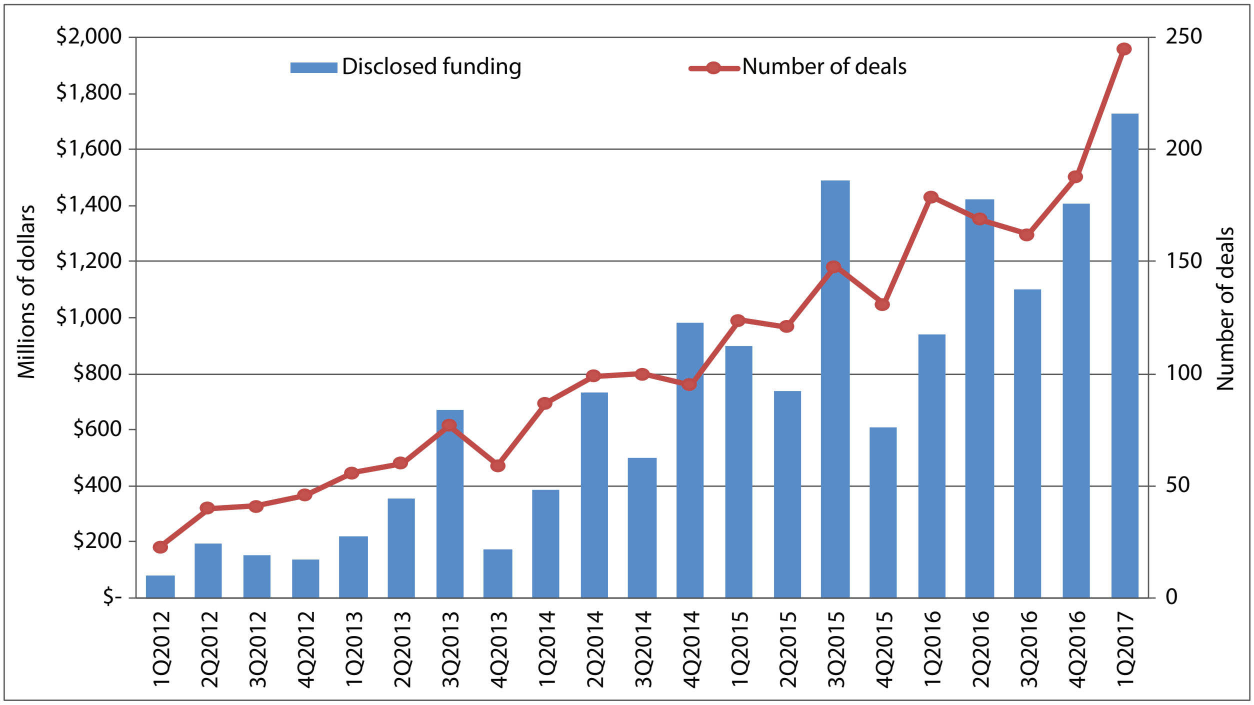
Many jobs and entire industries will be affected as the value of certain skills changes and as new business opportunities emerge. As in the past, workers whose skills complement new technologies can expect to see higher wages and better employment conditions. Who these workers will be, and what skill level they will have, depends on the nature of future technological change. The impact of technological progress on inequality will depend on which sectors and whose jobs will be subject to automation (see detailed discussion in the next subsection), how productivity gains translate into changes in demand, and how technological progress affects market structures and global patterns of specialization and trade.

From a technological perspective, future progress in key technologies such as artificial intelligence is almost certain, benefitting from the immense advancements in computer power,[31] an ever-increasing availability of data and the development and improvements of machine learning and other algorithms. Data on the amount of funding directed towards research in AI shows a clearly increasing trend (figure 5.1). This progress is expected to lead to the ability of robots and other machines to undertake an increasing number of tasks, to breakthroughs in materials and techniques such as gene editing, as well as the introduction of new consumer products.

Data on the economic impact of advanced technologies provides limited evidence of their large influence. For example, estimates suggest that industrial, physical robots have contributed an average of 0.37 percentage points to annual GDP growth and 0.34 percentage points to labour productivity growth in the United States, 14 European countries, the Republic of Korea, and Australia, between 1993 and 2007 (Graetz and Michaels 2015). More importantly, the study highlights the growing capability and pace of adoption of robots as the quality-adjusted price of robots declined by 80 per cent between 1990

31 The standardized costs of computation have declined at an average rate of 53 per cent yearly over the 1940 to 2014 period. Although the progress of computing power per chip may have slowed recently, this has apparently been offset by the advent of parallel computing and cloud computing (Nordhaus 2017).

Figure 5.1
Global quarterly artificial intelligence funding (millions of dollars) and number of deals, first quarter 2012-first quarter 2017



Source: UN/DESA, based on data from CB Insights (2017). "The 2016 AI Recap: Startups See Record High In Deals And Funding".

and 2005.[32] As robots become cheaper and more capable, while increasingly leveraging advanced technologies like AI, their contribution to economic activity is likely to rise further.

B. How will automation affect future employment?

There is significant uncertainty surrounding the extent to which new automation technologies will affect the workplace over the next few decades. A growing body of empirical work has sought to assess the quantity and types of jobs that are potentially at risk of automation. The results of these studies vary widely, depending considerably on the methodology used. Caution is therefore warranted when reporting and discussing estimates of the potential employment impact of automation.

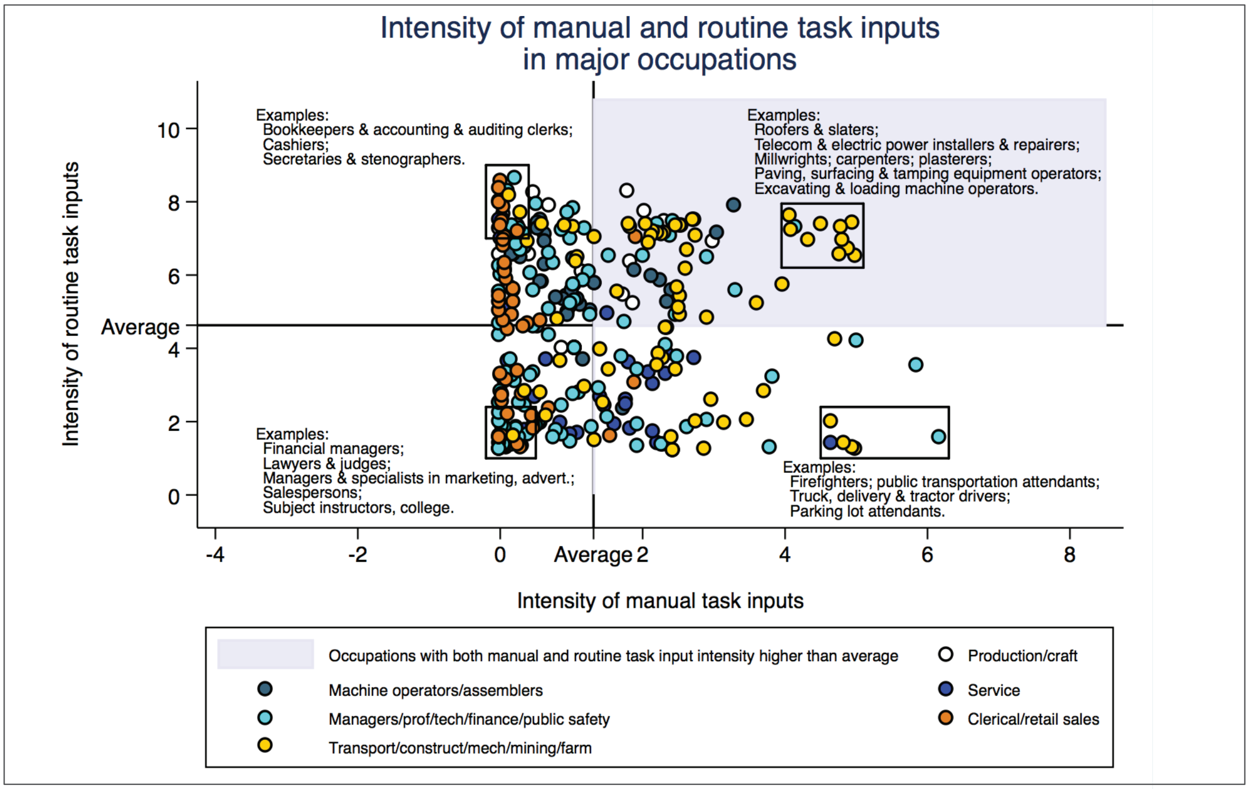
This is all the more important since most of the studies only estimate the job losses from automation and do not attempt to quantify potential direct and indirect job creation effects. As discussed in section 4, over the course of the previous industrial revolutions, technological innovations have led to large-scale job creation, both directly and indirectly. There is little reason to expect that this time will be different. AI and machine learning systems will likely create many new jobs across all sectors, particularly in developed economies. Most of these jobs will be in occupations that already exist, although the task requirements could change considerably. There is also the potential that entire categories of new jobs emerge as suggested in a recent global study by Accenture (Wilson et al. 2017).

The potential for job destruction

A useful starting point to examine the potential susceptibility of employment to automation is the previously introduced framework, which divides tasks along the two dimensions cognitive/manual and

32 Typical applications of industrial robots include assembling, dispensing, handling, processing, welding, agricultural harvesting, and inspecting.

Figure 5.2
Classification of major occupations according to routine and manual tasks



Source: UN/DESA, based on Autor and Dorn (2013).
Note: The data covers 330 occupations that are grouped into six major occupation groups as per Autor and Dorn (2013). Intensity of manual and routine task inputs are measured on a zero to ten scale. For the 5 per cent of occupations with the lowest manual task inputs, their manual task inputs are uniformly set to the 5th percentile. The label "average" on the x-axis and y-axis denotes the means of manual and routine task inputs across all 330 occupations, respectively.

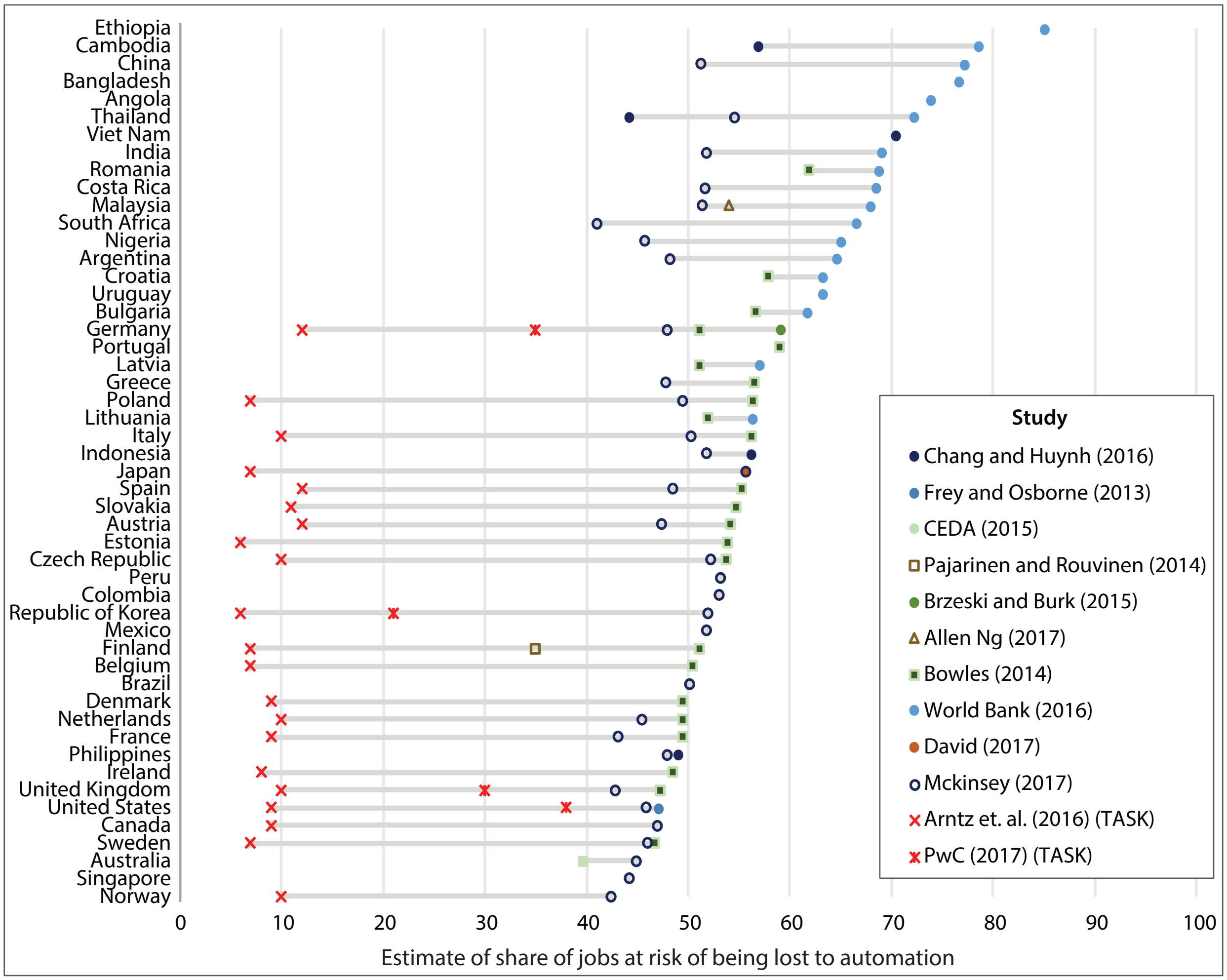
routine/non-routine (see figure 5.2). As indicated in section 4, it is primarily routine tasks—both manual and cognitive—that have so far been replaced by computers and robots. Non-routine, cognitive tasks that require judgment, problem-solving, intuition, persuasion or creativity as well as non-routine, manual tasks that demand a high degree of situational flexibility and human interaction have not been automated. This general trend will likely persist in the near future. However, the combination of big data, AI and rapidly expanding computational power makes automation increasingly viable in less routine tasks, such as diagnosing diseases, legal writing or navigating a car through busy streets (see for example Brynjolfsson and McAfee 2014).

In attempts to move past this two-dimensional categorization, more complex task-oriented frameworks have recently been developed. McKinsey Global Institute (2017), for example, assesses 18 technical capabilities that are required to substitute tasks performed by humans. These capabilities are grouped into five categories: sensory perception; cognitive capabilities; national language processing; social and emotional capabilities; and physical capabilities. In this framework, the least automatable tasks are related to social and emotional sensing, complex problem solving, coordination of group activities, creation of novel ideas, and movement across various environments and terrains.

Several new studies estimated the proportion of jobs that are susceptible to automation in the next two decades. In doing so, two different methodologies have been used: an occupation-based approach and a task-based approach. The occupation-based approach

Figure 5.3

Range of estimates of the share of jobs at risk of being lost to automation from artificial intelligence and advanced technologies, by study and methodology



Source: UN/DESA, based on various studies.

Note: (TASK) refers to studies that estimate the effect on jobs using a task methodology. All others rely on a survey that ranks entire jobs being at high, middle or low risk of being automated. See Arntz et. al. (2016) for further explanation.

was first applied in a seminal empirical study for the United States by Frey and Osborne (2013, 2017). Although they initially characterize occupations by the tasks involved, they ultimately assume that whole occupations are automated.

The authors' main—and widely discussed—result is that 47 per cent of all jobs in the United States have a high risk of being automated over the next 10 to 20 years. Using similar methodologies, Bowles (2014), Chang and Huynh (2016), World Bank (2016), and Ng (2017) find that in the European Union, and particularly in developing countries, an even higher share of jobs is at high risk of automation in the next decades.[33] Studies that applied the occupation-based approach proposed by Frey and Osborne (2013, 2017) have very high estimates of the share of jobs that is at risk of automation, ranging from 35 per cent in Finland to 85 per cent in Ethiopia (see figure 5.3).

33 In the case of the EU-28, Bowles (2014) estimates that 54 per cent of all jobs are at risk; for the five ASEAN countries, Chang and Huynh (2016) find that 56 per cent of total employment is at risk; and for Malaysia, Ng (2017) estimates that 54 per cent of all jobs are at risk.

Frey and Osborne's assumption that whole occupations, rather than tasks, are automatable has been criticized on the grounds that such an approach likely leads to an overestimation of potential job losses due to automation. In reality, workers within the same occupation often perform very different tasks.

Arntz et al. (2016) therefore follow a task-based approach. Since many workers perform a significant share of less automatable non-routine tasks, their approach yields much lower estimates for the share of jobs that are at risk of automation—on average, only 9 per cent in OECD countries.[34] Using the same methodology, but an alternative model specification, (Berriman and Hawksworth 2017) find that the share of jobs at risk ranges from 21 per cent in Japan to 38 per cent in the United States—figures that are below the estimates from occupation-based approaches, but well above the Arntz et al. (2016) estimates (figure 5.3).

While the expected economy-wide impact of job automation varies greatly, there is some consensus on the sectors and types of workers that are most at risk. The actual impact will depend on country-specific factors, including the sectoral employment structure. Automation will likely remain strongest in the manufacturing sector (in particular affecting assembly line workers), but is also expected to increasingly affect different parts of sector service jobs.

Based on recent empirical studies, the following sectors appear to be particularly vulnerable to automation: wholesale and retail trade; administrative and support services; manufacturing; transportation and storage (see for example Frey and Osborne 2013, 2017; Berriman and Hawksworth 2017). On the other hand, sectors with low automation risks are education and training; human health and social work; and agriculture, forestry and fishing. As pointed out by Chang and Huynh (2016), there are prominent occupations in some countries that face exceptionally high automation risks. This includes, for example, sewing machine operators in Cambodia's large garment sector and office clerks in Indonesia.

What types of workers are likely to be most affected by automation? Some studies suggest that in both developed and developing countries, workers with low and medium levels of education face greater risks of job automation (Berriman and Hawksworth 2017; McKinsey Global Institute 2017; Ng 2017; Chang and Huynh 2016), given that they make up the bulk of the workforce in the sectors that are potentially most affected.[35] This result supports the notion that higher education helps develop skills and competencies that are useful to perform more complex tasks requiring advanced levels of perception as well as creative and social intelligence—tasks that are considered difficult to automate.

Available empirical evidence also supports this view. In a study of the speed of automation and its effects on manufacturing employment in OECD countries, Graetz and Michaels (2015) find the growing use of robots between 1993 and 2007 was associated with a reduction in the numbers of hours worked by low- and middle-skilled workers, whereas high-skilled workers were not affected. Acemoglu and Restrepo (2017), in a study on the impact of robots on labour markets in the United States, also find that in the manufacturing sector automation has a negative and significant effect on employment and wages of the low skilled, but not of the high skilled.

Looking beyond manufacturing, they also find a significant negative impact of exposure to robots on employment in local labour markets, even if controlling for globalization and non-technology related effects, with men being more negatively impacted than women.[36] Based on existing estimates, the relative impact of automation on men and women seems to differ between developed and developing countries. In the case of developed countries, men are found

34 The highest shares are found for Germany and Austria (12 per cent), the lowest for the Republic of Korea and Estonia (6 per cent).

35 As in the recent past, many of the occupations that appear most susceptible to automation over the next two decades are in the middle-wage category.

36 It should be noted that these papers study the labour market impacts of automation on sectors and/or specific locations, but not on economy-wide employment and wages.

to be more at risk than women given their overrepresentation in transportation and manufacturing and their underrepresentation in education, health and social work. By contrast, Chang and Huynh (2016) indicate that in five ASEAN countries, women face greater odds of being in high-risk jobs than men. This reflects women's strong presence in low-skill, low wage sectors such as garments and footwear, and sales that face relatively high automation risks.[37]

While most analyses suggest that AI and other new technologies will continue to benefit higher-skilled workers, an alternative scenario cannot be ruled out. Similar to what happened in the first two technological revolutions, future automation could increasingly displace highly educated and skilled professionals. Noting that the rote tasks of any information-based job can be automated, Kelly (2016) projects that AI robots will start to gradually replace doctors, translators, editors, lawyers, architects, reporters and even programmers. In the health sector, AI-powered machines could diagnose health problems and robots perform surgeries, while humans undertake relatively lower skilled nursing tasks.[38] If such projections materialize, they will imply a shift in which services replace manufacturing as the sector most affected by automation.

C. Economic and other barriers to automation

The bulk of available empirical studies focuses on the technological feasibility of automation, without assessing economic, legal, regulatory or socio-political barriers. Just because a job could be eliminated, does not mean it will be eliminated. In many cases, where automation is technologically feasible, it may not be economically optimal. Firms will weigh the benefits of new automation technologies (for example a lower wage bill or higher productivity) against their costs, often in an uncertain environment and with incomplete information. The adoption of new technology requires absorptive capacity and can involve significant costs including for material, employee training and production shutdowns (see for example Hall and Khan 2003). With uncertainty about demand and the ability to recoup these costs, firms may be unwilling to incorporate labour-saving technology even if it has the potential to improve productivity.

In terms of potential benefits, an important factor in a firm's decision-making process is the cost of labour. This partly explains why developing countries with abundant cheap labour have so far not been visibly affected by automation. The generally low level of wages in many developing countries, particularly in the service sector, will also help to stave off automation and job displacement going forward.

There are also immense legal and regulatory issues that need to be addressed for automation technologies to have a more far-reaching impact. The most prominent example is driverless vehicles, where the liability for accidents is difficult to resolve. For AI to be deployed on a large scale in healthcare, it must be decided who will be responsible when something goes wrong. Finally, there are often powerful interest groups, including trade unions, that fight to protect some workers and industries against the negative effects of automation.

D. Other possible long-term implications for employment and inequality

Essentially, all present data is fully consistent with the view that 'this time is not different'. Despite uncertainty on timing and details, the current times can be characterized by rapid technological progress that is disruptive as it leads to job creation and destruction, but also ensures steady, though unbalanced, progress in productivity, wages, and employment. Nevertheless, alternative scenarios should not necessarily be dismissed.

One view characterizes the current prospects by a lack of true technological progress. While Gordon (2012) and others acknowledge the introduction of

37 For the case of Malaysia, Ng (2017) finds about the same automation risk for women and men.

38 While robots are already assisting in operating rooms, control has so far remained in the hand of the surgeon. As the machines improve, a trained technician could at some point be able to oversee the surgery and ultimately robots could be fully in charge.

new products and production processes, they claim that these do not have the same economy-wide productivity effects as key technologies in earlier periods, such as the steam engine, electricity or the computer. A main line of support for the pessimistic view is the productivity slowdown discussed in section 3. However, the productivity slowdown does not have to be seen as a sign of the lack of technological progress, as long as it is temporary. In fact, as Eichengreen (2015) argues, technological revolutions are often associated with an initial slowdown in aggregate productivity, as fundamentally new technologies require new infrastructure, new skill-building and new business models before they develop their full impact on production structures. Importantly, even if technology plays a role in the aggregate productivity slowdown, it does not imply a lack of new innovations with productivity enhancing potential. Andrews et al (2016) identify a reduction in technological diffusion as a key factor behind reduced aggregate productivity. Technologies are developed and quickly adopted by leading firms across the globe, but are adopted much slower by firms lagging behind the technological frontier.[39] This lack of diffusion could be due to the 'winner takes most' dynamic in new technology sectors (see section 4.D), but also due to increased barriers of entry caused by difficulties for laggard firms to undertake complementary firm-specific investments needed to benefit from new technologies.[40]

Others believe that the new technologies will lead to acceleration in productivity growth, with stronger implications on labour markets and income inequality than in the past. Brynjolfsson and McAfee (2011) and others are of the view that new technologies mean faster and better measurement, faster business experimentation, more efficient spreading of ideas and easier scaling-up of successful innovations. As these effects multiply each other, they can accelerate productivity gains once organizational setups adapt.

The consequences of technology-driven productivity acceleration could indeed be different than what we observed in the past. Recently, Nordhaus (2017) explored the issue under the label 'economic singularity', alluding to the concept of technological singularity,[41] which is popular among technologists. With singularity, new machines would not just automate existing tasks as in the past, new machines would also create and undertake new tasks, whereas currently the process of developing new tasks is done by humans as it requires intelligence.

From an economic perspective, singularity requires that capital and labour (and other scarce inputs) cease to be complements and become substitutes and that technological progress makes machines ever more productive. Evidence for the United States reveals that singularity has not happened (yet) and based on current trends, is unlikely to happen within the next century, if ever. While there is no conclusive evidence on the economy-wide substitutability between capital and labour, most estimates find them still to be complements.[42] Moreover, singularity would lead to rising productivity growth, but as noted in section 3, productivity growth is actually slowing. In addition, if people were to invest more and more in new machines as they become ever more productive, the ratio of capital to total output should accelerate, whereas the ratio currently is actually declining.[43]

39 Comin and Ferrer (2013) documented a decrease in the time it takes for technology to be adopted across countries in the last two centuries. For example, while it took 11 years after the invention of the computer for it to be adopted in Vietnam, it took over 120 years for the steam engine to make its way from the United Kingdom to Indonesia. However, the time for diffusion of technologies after the initial adoption within a country has increased.

40 It should be stressed that there are also non-technology related factors behind the productivity slowdown, which may be dominant. Adler et al. (2017) identified repairing balance sheets and disruptions of credit mechanisms in the wake of the recent global financial crisis as key, while also stressing the importance of secular factors.

41 Singularity in computer science describes the point when computers become smarter than the best human brains in practically every field, so that subsequent machines would be developed by machines rather than humans.

42 However, Karabarbounis and Neiman (2014) find that capital and labour are already gross substitutes, a result also used by Piketty in his famous book on inequality (Piketty 2013).

43 However, some current trends are consistent with singularity, namely the rising share of capital in total income discussed in section 3 as well as the rising share of information capital in total capital.

The facilitation of greater adoption and diffusion of new technologies will lead to accelerated progress. In such cases, the implications on inequality depend on which group of workers can more easily be replaced by new machines and how the overall gains are shared. If low-skilled workers are more easily replaced, their wages would decline, ultimately below the point where people would be able or willing to work at all. Skilled workers, however, would continue to be employed and would, in fact, see rising wages. At the same time, their share in total income would nevertheless fall, as returns on capital accruing to the owners of the new machines will increase even faster than wages. In fact, the ever-increasing inequality between different groups of workers and between workers and technology owners in such a scenario might easily lead to protracted societal conflicts. Ford (2016) warns against the risk of a "perfect storm" as the effects of technological unemployment and rapidly rising inequality unfold in parallel with climate change and resource depletion. If, on the other hand, machines would more easily replace high-skilled workers performing cognitive tasks, skill building through education would become futile, as the only jobs available would not require specific skills. In such a scenario, wage inequality would actually decline. However, the inequality between capital owners and workers would still increase dramatically and could potentially lead to societal conflict, unless the profits were to flow to workers in the form of dividends or through redistribution.

E. Technology, automation, and global production patterns

From a developing country perspective, the impact of rapid technological change on labour markets depends not only on technological changes in their own countries, but also on how technological change in other economies affects global production and trade specialization patterns. Worldwide, firms have invested in technology and automation in a bid to remain competitive or to proactively address rising labour costs. Automation has happened quickly in industrial powerhouses and in industries where routine jobs can be more easily replaced, such as the automotive, electrical and electronics manufacturing, and metal and machinery industries.

Based on data from the International Federation of Robotics (IFR), global sales volume of industrial robots has accelerated from an annual average of 5 per cent between 2005 and 2012 to 16 per cent per year between 2012 and 2016. Three factors have contributed to this acceleration. First, robots are becoming cheaper. Second, their capabilities are expanding with technological improvements in, for example, machine vision, sensors and motors. Third, an ageing population and increases in labour costs in some manufacturing countries, together with competitive pressures, have led to a rising demand for automation.

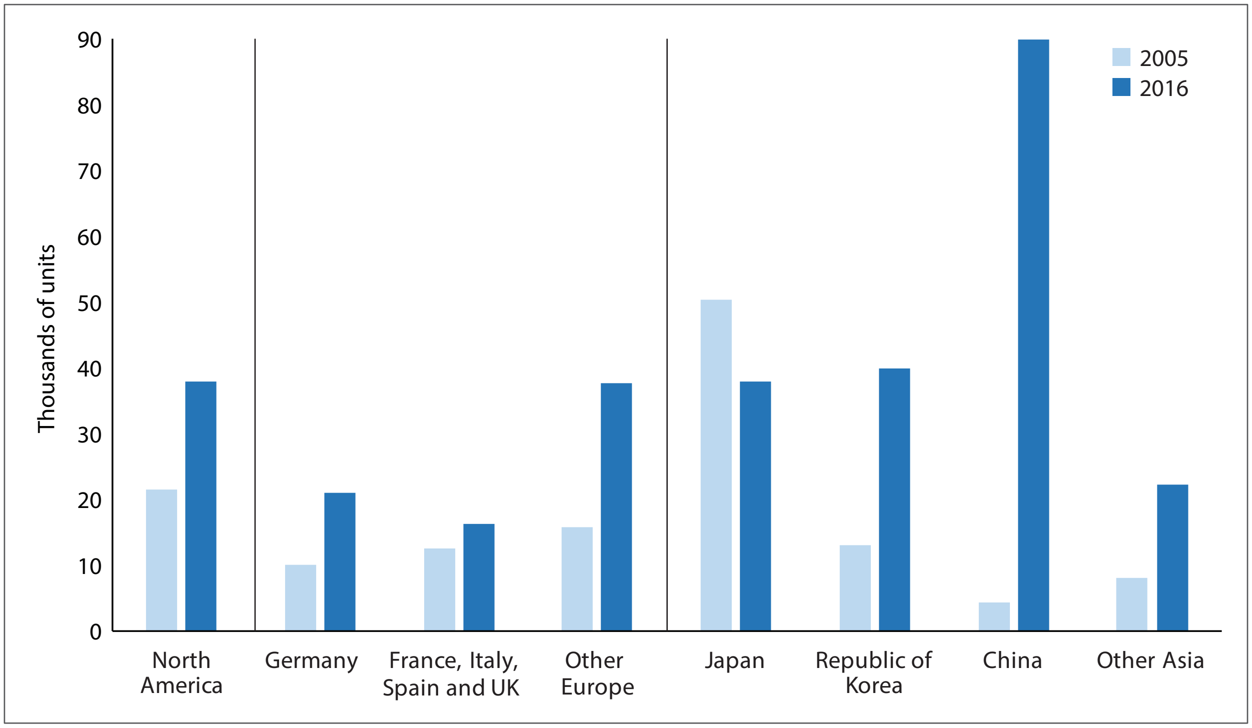
These factors are not only in play in developed countries, but also increasingly in developing countries that have established themselves as leaders in global manufacturing.

Notably, China has led the world in the purchase of industrial robots, with its demand rising by an annual average of 31 per cent between 2005 and 2016 (figure 5.4). Chinese firms are also expected to absorb 40 per cent of the global supply of industrial robots in 2019 (IFR 2016). China's manufacturing sector still has ample room to introduce robots as its proportion of robots per industrial worker (robot density), with just 49 per 10,000 employees, is below the global average of 69, and an order of magnitude below the Republic of Korea, with 531 units per 10,000 employees. The heavy investment by Chinese firms is in line with the country's 10-year plan ("Made in China 2025") to become a major technological industrial manufacturer and to shift China's comparative advantage away from labour-intensive manufacturing.

Amid a continued acceleration of global demand for industrial robots, robots are also increasingly being used in the service sector, particularly in the logistics sub-sector (figure 5.5). This in tandem with the growing complexity of global supply networks, which demands a high efficiency in operations and production management. Nevertheless, industrial robots are likely to still dominate the global use of

Figure 5.4

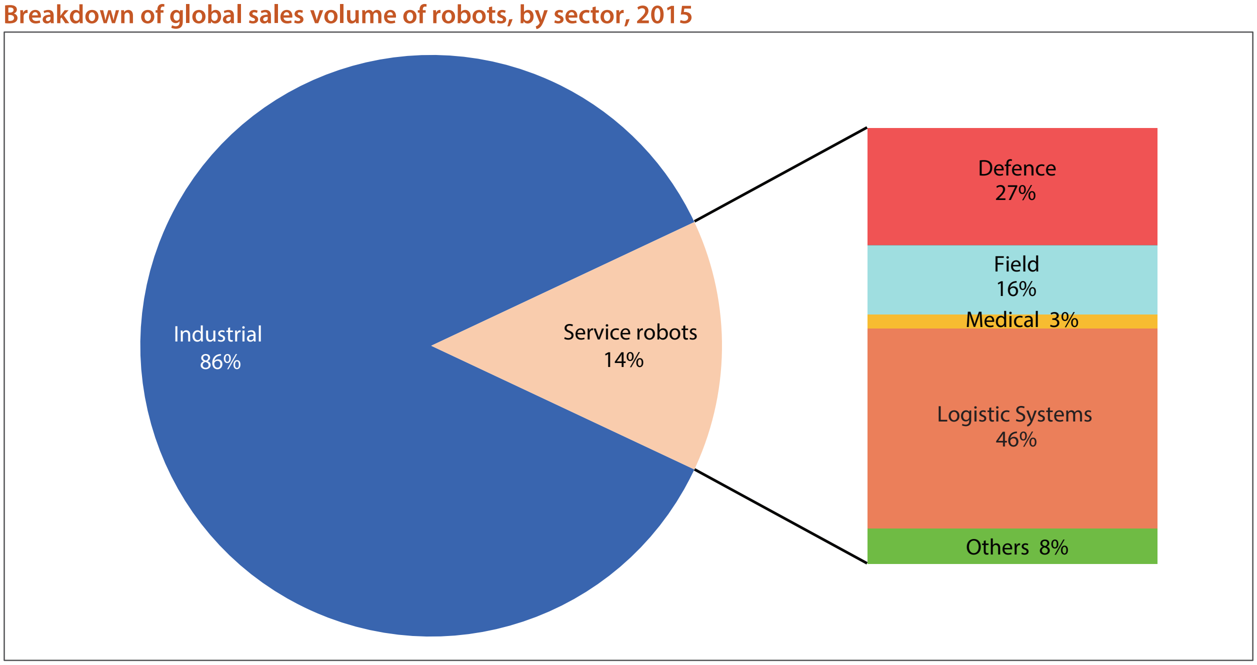
Demand for industrial robots by selected countries and regions, 2005-2017



Source: UN/DESA, based on data from International Federation of Robotics.

Figure 5.5

Breakdown of global sales volume of robots, by sector, 2015



Source: UN/DESA, based on data from International Federation of Robotics.

Note: Service robots are those used only for professional services.

robots given that many service jobs require close human interaction which is more difficult to be taken over by machines.

This process of automation will continue to shape what and where goods are produced

This process of automation and the greater adoption of advanced technologies like AI in manufacturing will continue to shape what and where goods are produced, defining the geography of global value chains. As discussed in section 4.C, the impact of this trend on global production patterns depends on the complex interaction between technological progress and trade.

Increasing labour productivity and the resulting rise of wages in China is creating opportunities for poorer developing countries in labour intensive manufacturing where the use of robots is not economically viable (e.g., major segments of garment-making). In these industries, automation has yet to create competitive pressure and countries with a surplus of low-cost labour retain a cost advantage. In this sense, poorer developing countries can be expected to benefit from a lack of technological progress on certain global markets. While this allows these countries to better absorb large numbers of lower-skilled workers, it doesn't provide the competitive incentives for firms to invest in new technology and relegates their manufacturing sectors to less sophisticated industries.

Many other sectors within manufacturing, however, provide ample scope for automation. It is notable that the same industries where robots are being introduced are the ones that were susceptible to the fragmentation of production in the global value chain (GVC) (Frey et al. 2016). It is therefore reasonable to expect that automation will change global production patterns and impact the ability of smaller firms and countries to remain competitive in the GVC. Only countries with dynamic export sectors, composed of firms with the internal capabilities to innovate and react, will be better positioned to take advantage of changing relative factor costs caused by new technologies. Hence, technology-driven automation may limit the number of sectors in which poorer developing countries can gain a competitive advantage, if the share of global production undertaken in GVCs continues to rise.

Technological progress also allows for the reshoring of production

The same process that allows firms in many countries to invest in technology and enter export markets also works in reverse, creating incentives for manufacturers to "reshore" their operations closer to main markets. In developed countries, technology-driven automation, the rapid deployment of industrial robots noted above, and new production technologies such as 3D printing have reduced the cost of final products. At the same time, labour costs in China and other Asian countries have increased. In some industries, labour cost differentials may no longer be sufficient to justify offshoring, and gains from advanced manufacturing methods can justify a reshoring of production. For example, technology has allowed manufacturing firms in the United States to remain competitive, maintaining steady output despite a decrease in manufacturing employment (Frey et al. 2016). However, whereas production is to some extent re-shored, employment is not.

Whether reshoring will occur on a massive scale is not yet clear. Several factors may have delayed reshoring projects: weak economic growth in the last decade, a slow pace of investment, and the lack of supplier networks. In addition, the size and growth of consumer markets in countries that have well-developed supplier networks remain important for off-shoring and reshoring decisions (Cohen et al. 2017; De Backer et al. 2016).

The gains in manufacturing may become concentrated, increasing inequality, and contributing to premature deindustrialization

The relative trends in automation and labour costs will likely lead to further competitiveness gains for the existing industrial powerhouses of the Republic of Korea, Germany, China, Japan, and the United

Box 5.1

LDCs and the technological revolution

When you're next driving the clogged streets of Kinshasa, Democratic Republic of Congo, don't be surprised if you run into an eight-foot high solar-powered traffic robot. Five locally-designed automatons stationed throughout the capital each do the job of four traffic lights. Fitted with camera eyes that monitor and record drivers, they play pre-recorded messages to pedestrians, letting them know when it's safe to cross the road.

The robocops are welcomed by local people – not only because they improve safety but because they never get tired and they don't take bribes. The next logical step, speculates the New York Times, would be to give them artificial intelligence and to transfer the technology to other jammed African streets (Okorafor 2016).

Kinshasa's robots are proof that even the least developed countries (LDCs) are not immune from the so-called fourth industrial revolution. New technologies are affecting a range of economic activities.

Agriculture, where 60 per cent of LDC employees work, is the sector in which new technologies could have the greatest impact. Drones have the potential to scout crops and to reduce the work involved in seed planting and fertilization, raising yields. Automated irrigation systems can enhance precision and reduce manual labour. The genetic modification of seeds, although controversial, can increase disease-resilience, flood and drought resilience and thus increase yields.

It is not just agriculture: the biggest economic challenge confronting the world's 47 LDCs is the move from low- to high-productivity activities, the process by which East Asian and developed countries industrialised through technological catch-up (UN Committee for Development Policy 2017). In recent decades, most LDCs have been excluded from this traditional route to development, experiencing a shrinkage of manufacturing and a rise in underemployment as people moved from the countryside to towns and took up semi-formal services jobs.

Additive or 3D manufacturing has the potential to address many of the problems of industrialisation in LDCs, namely isolation, distance from major markets and low economies of scale. Flexible manufacturing processes require lower investment than old, specialised machines. The absence of tooling costs reduces fixed outlays and facilitates small production runs.

Technological know-how, training and open-source designs can be found for free online. Even the cost of importing inputs may not be insurmountable. Some products can be 3D printed using recycled plastics rather than expensive foreign polymers.

Yet the very labour-saving and productivity benefits of the robot revolution represent a threat to countries with abundant labour supply.

Just at a time when rising Chinese labour costs presented an opportunity for LDCs to industrialise by attracting low-wage manufacturing, some of those jobs are likely to be mechanised. As noted elsewhere in this report, China is the world's biggest market for industrial robots, while some previously outsourced jobs are beginning to be 'reshored' to developed countries.

Even if LDCs stand to benefit from the productivity gains associated with the fourth industrial revolution, it is not productivity per se that they need; it is jobs. Youth unemployment in LDCs is over 10 per cent on average, according to the World Bank, having gradually worsened since 1980. Informal or part-time work is much higher. These high rates of joblessness are not only undesirable in themselves but bring associated social problems and political instability.

Lant Pritchett of Harvard University argues that tech entrepreneurs should not be aggravating the unemployment problem. The technological revolution is not an inevitable process, driven by market forces. "The technologies pioneered and developed in the US and Europe and Japan then blow back into poor countries," says Pritchett. "We cannot continue to ignore the obvious that technological progress is being driven in rich countries by distorted prices and availability of labour and is then inefficiently and uneconomically destroying jobs all over the world" (Pritchett 2017).

(*continued*)

Many LDCs do not yet possess the required skills, energy infrastructure, broadband or transport networks to take advantage of the new production techniques. Investment rates in LDCs remain lower on average than in developing countries—and below the rate required to spark structural transformation. Just as in previous waves of technological advance, in the absence of policies to mitigate the negative impact from rapid technological change, many peripheral nations will miss out.

Not many LDCs are at a point where a robot, with its significant electricity and maintenance costs, will replace a traffic policeman on a few dollars a month. Many potential workers are waiting to take those jobs. Ultimately it may be the very defining characteristics of LDCs which insulate them from the full impact of the fourth industrial revolution for good or ill: their cheap wages, lack of infrastructure and weak human resources.

Governments in LDCs and international agencies are challenged by the need to support net job creation and to simultaneously promote the adoption of new technology to improve health and a safe environment.

Source: Gay, Daniel. 2017. "LDCs and the Technological Revolution." *Support Measures Portal for Least Developed Countries*. August 30. www.un.org/ldcportal/ldcs-and-the-technological-revolution/.

States (Sirkin et al. 2015, Frey et al. 2016). There is a risk that this may lead to a widening gap in competitiveness and growth rates over longer time periods. Hence, while historic patterns suggest that global production would shift towards poorer developing countries in line with increasing wages in emerging countries such as China, increased automation in these countries will reduce the scope for poorer developing countries to establish themselves in manufacturing.

As seen in section 3, many developing countries have seen their share of manufacturing employment and output shrink earlier than was experienced by developed countries and emerging economies in the past.[44] The competitiveness of international markets, the emergence of GVCs and the relative ease of standardizing manufacturing processes across borders have contributed to the rapid pace of automation in all manufacturing countries. This, in turn, is contributing to the global decline in labour intensity in manufacturing (Rodrik 2013, 2016). Because of this premature and widespread decline in the share of manufacturing jobs in developing countries, their manufacturing sectors will likely support fewer jobs than observed in developed and earlier emerging economies in the past. In this case, countries will find it difficult to grow using the traditional roadmap of shifting workers from agriculture to manufacturing. This will likely lead to a divergence in incomes between countries in Asia, with already large manufacturing sectors, and those in Africa and South America.

44 Industrialization, or the shift of labour from agriculture into manufacturing sectors, is a central mechanism by which countries are able to achieve higher growth rates and incomes. It is often measured as the share of manufacturing employment and varies with national income in an inverted-U shape, at first increasing with incomes until it reaches a peak.

6 National policies and need for global cooperation

As previously discussed, technological innovation is a main engine of productivity growth, but can also be a major force of disruption. How the new wave of technologies will shape labour markets and income distribution, ultimately depends on the institutions and policies that are in place at the national and global level. In devising policies and shaping institutions, Governments need to take into account that they operate with significant uncertainty, and this would support a trial-and-error approach that can be adapted according to new experiences and developments. Overall, Governments play an active role in promoting the development and use of new breakthrough technologies. At the same time, they must ensure that the gains are broadly shared and that displaced workers can find new, high-quality jobs.[45] The kind of policies and institutions that will best achieve these ends will depend on country-specific conditions.

A. Government policies towards new technologies

Governments play a crucial and direct role in fostering innovation-led growth. According to Mazzucato (2013), the state is not only a facilitator, but a catalyst of innovation. Governments can create and shape markets, rather than merely fix them. Underlying this view is the notion that the so-called "entrepreneurial state" played an important role along all stages of the innovation chain: from basic and applied research to commercialization and the financing of start-up companies. Many recent technologies, including the global positioning system (GPS), the voice-activated personal assistant and the algorithms used by Google, benefited from government funding in the early stages. The private sector often only invested in potential breakthrough technologies once Governments had made the initial high-risk investments.[46]

In addition to this direct role in technology development, Governments in both developed and developing countries also play a critical facilitating role by creating an environment to ensure the development, adaptation and diffusion of new technologies appropriate to their own country context. Policy measures to consider include the support to national (public and private) institutions of research and innovation, provision of infrastructure (e.g., broadband), support to business incubators that enable start-up firms to bring new technologies more quickly to markets or the promotion of networks of firms and non-state actors.[47] In many countries, new technologies are often restricted to foreign firms and a few large domestic firms. However, as industrial development typically requires both local capabilities and foreign investments, governments are called to promote national capacity to innovate, including among small firms.

All countries have what has come to be called a national innovation system (NIS), which encompasses the educational system, scientific and technical research institutions, private firms' product development departments and other mechanisms through which products and production processes are redesigned. A key responsibility of an effective NIS is building domestic capacity to choose, absorb and promote the technologies that are most conducive to enhancing dynamic sustainable development.[48]

Subsidies or tax incentives for consumers as well as preferential regulatory measures can also promote the adoption and diffusion of new technologies.[49] As sectors vary with respect to economic linkages and possibilities for technological upgrading, there is also scope for targeting specific sectors through technology policies. Focus should be on industries that have dynamic linkages to other economic sectors, thereby stimulating overall growth and employment creation, thus broadening the gains from technological progress. With the emergence of new technologies, the traditional narrow focus on manufacturing will likely forgo opportunities to build better integrated service sectors to spur productivity growth in the primary and industrial sectors as well.

New technologies may also require new regulations addressing questions of liability and ethics. Should manufacturers, hospitals, doctors or patients be held responsible for the consequences of following the medical advice of an AI-powered device? The liability question of self-driving cars also features prominently in the public discussion. Optimal regulatory

45 The same argument is often made for globalization, which – as previously discussed – is closely connected to technological innovations.

46 Mazzucato (2013) and other proponent of this view acknowledge that governments' innovation projects often fail – just like those of private firms.

47 See Nurse (2016), for example.

48 For a full discussion on the importance of national innovation systems for development, see United Nations (2011).

49 Norway's rapid transition to electric vehicles, for example, has been built on a broad range of government incentives. These include the exemption from a 25 per cent sales tax, bus-lane access for electric cars and privileged parking.

responses may not be straightforward, which calls for an experimental approach in which regulatory reforms are first tested in certain markets. The increasing importance of data as driver of AI and economic activities requires regulations that effectively ensure privacy as well as security without stifling innovation.

Regulations regarding intellectual property rights (IPRs) also affect innovation. Patents, copyrights and trademarks are meant to promote innovation by allowing firms to capture a larger share of the returns to their research investments for a specified period in exchange for making their inventions public. However, IPRs may also stifle innovation by locking in the advantages of incumbents and preventing other firms from building on newly-invented technologies. This problem appears to be particularly relevant in the information and communication technology industry. At the same time, new information technology developments often utilize open-source software and other non-proprietary technologies, which can contribute to the rapid diffusion of new technologies and the lowering of barriers to entry for new firms. The field of biotechnology may also be characterized by negative effects of IPRs on subsequent innovation (Williams 2013).[50]

Antitrust regulations may need to be reconsidered to ensure they remain appropriate for the new business models enabled by technology. Existing antitrust policy can play an important role by preventing firms from using a dominant position in markets caused by patents to restrict competition. However, regulatory regimes also need to address the possible lack of competition that can arise from network effects. In addition to standard antitrust policies, there may also be scope for new policies such as assigning ownership rights in a pro-competitive way. For example, if contacts on social media belong to the individual who establishes them rather than the social media platform, it may be easier for consumers to switch to new firms. This, in turn, could increase competition in the market (Rolnik and Zingales 2017).

B. Labour market policies

Education and (re-)training

Technological change is reshaping the demand for skills in the labour market and, in order to remain competitive in jobs that are complemented by AI, workers must acquire the necessary skills during their schooling or as part of job training.

Providing the appropriate skills to current and future workers is an important area for policy. The supply of labour at each skill level is affected by the educational system and on the job-training. Greater access to tertiary education and vocational training would ensure access to jobs that demand higher skills. Adaptation of the education curricula to reflect the skills that will be in demand in the future is also important. Greater focus on science, technology, engineering and math (STEM) education is a requirement for the new technologies and early exposure to computer science, entrepreneurship and interpersonal skills can help prepare the next generation of workers. Beyond the acquisition of formal skills, the speed of technological progress requires greater flexibility from workers and fast learning. Policies to support early education and life-long learning skills are critical. In most countries, developing countries in particular, strengthening the educational system to meet the challenges of new technology will require the hiring and retention of quality educators, proper funding for educational institutions, and high standards for student achievement.

Education and training systems must prepare workers to be flexible and to develop new skills in response to rapid changes brought by new technologies. Policies can provide the incentives and the means for workers to get additional training and education in not only technical areas, but also creativity, management, social and communication skills. The availability of low cost online courses has greatly expanded the opportunities for continuous learning where workers learn new skills and invest in their own human capital. Public education institutions are yet to make

50 There is also a debate on the general impact of patents on innovation and productivity. Boldrin and Levine (2013) are not able to find positive impacts, a finding they characterize as a "case against patents". Watzinger et al. (2017) show that patents held by a dominant firm can be harmful for follow-on innovation.

better use of this same technology to improve education outcomes. Incentives for firms to invest in the education of existing and new workers, such as dedicated time and subsidies should also be considered. Public expenditures in active labour market programmes (training and job search, for example) can also support workers during job transitions. This indicates a need to shift policy focus from "passive" towards "active" labour market policies.[51] For example, in 2015, OECD member countries spent an average of 0.78 per cent of GDP on "passive" measures, but only 0.53 per cent of GDP on "active" measures, and 0.13 per cent on training (OECDstat 2017).

Protecting unions and labour standards

As noted in section 4, a growing number of workers have more flexible, but also more insecure and precarious work arrangements, with new technologies being one of the main drivers for this trend. These non-standard work arrangements have fewer worker benefits and welfare protection, which adds to the insecurity and vulnerability of workers. The characteristics of non-standard work arrangements discourages collective representation leaving workers in a weak bargaining position to negotiate their wages, and improve their working conditions. Traditionally, it is unions that give all workers greater power to negotiate a fair share of economic rents and of the gains of greater productivity due to technological progress. New forms of workers' representation are needed at a time when economic rents from new technology, as discussed in section 4, are contributing to a declining labour share in national income.

Governments can also undertake legal and tax reforms to strengthen the rights of workers in non-standard work arrangements. For example, a recent report on the future of work in the United Kingdom (Taylor et al. 2017) proposed enshrining a special status for "dependent contractors" in law that can be used to apply and enforce minimum wage regulations for these workers. The commission also proposes to facilitate the access of these workers to courts in cases of conflicts with employers and to remove incentives in the tax system that favour a classification of workers as self-employed.

C. Social protection and fair distribution

To the extent that systems of social security in many countries are tied to standard labour relationships, the increase in non-standard employment (whether technology-driven or not) as well as informal work particularly in many developing countries, leaves many workers without sufficient protection against illness, employment loss and pensions. Consequently, social security systems are in need of reform to extend protection to workers in non-standard and informal jobs. Whereas developed countries have started to review social insurance systems to ensure all workers have access to health care, unemployment insurance and pensions[52], progress towards universal social protection systems needs to accelerate in developing countries to extend coverage to workers in non-standard and informal employment.

While recent trends towards higher inequality in most countries has multiple causes, rapid technological change has contributed to increased wage inequality among workers, as well as between workers and firm owners. Progressive tax policies could ensure that benefits from new technologies, such as AI, are more widely shared. More progressive tax systems have the potential of generating substantial public resources for redistribution and financing of universal systems of social protection. Reducing taxes on labour generally encourages employment, reducing the need for redistribution, whereas taxing new technologies risks reducing economic growth

51 "Active" measures include public employment service and administration, training, employment incentives, sheltered and supported employment and rehabilitation, direct job creation, and start-up incentives. "Passive" measures include out-of-work income maintenance and support as well as early retirement. OECD.stat series "Public expenditure and participant stocks on LMP".

52 For example, the European Commission has started a public consultation of social partners on access to social protection as part of their initiatives on the European Pillar of Social Rights (European Commission 2017).

and technology adoption, reducing sources for redistribution. Instead, taxing rents and high profits arising from concentrated market structures may be more conducive to balance social and economic objectives. Taxing natural resources and environmental pollution can also generate resources for redistribution, while steering technology development towards sustainable development.

The fear of mass unemployment caused by technology, particularly as AI becomes more capable, has also motivated more radical proposals to reform existing social safety nets. The proposal most closely associated with the impact of technology on jobs is that of a universal basic income (UBI), whereby every individual would receive an unconditional cash grant.[53] This proposal would serve to guarantee a minimum level of income regardless of employment status and simplify the administration of various public programmes. This proposal remains controversial, as the idea of an UBI may substitute the provision of basic public services at lower protection levels. In addition to questions on implementation, discussions on UBI in the context of a technological revolution also need to consider that technological progress may destroy jobs with wages far above any reasonable UBI level.

Other proposals, associated for example with Varoufakis (2016), attempt to directly distribute profits more equitably with a 'universal basic dividend'. Under this strategy, a fixed share of new equity issuances by firms is placed in a public trust, generating an income stream which is then distributed evenly among segments of society. When studying such proposals further, possible trade-offs between encouraging competition (to reduce prices and increase product variety in the future) and allowing firms to restrict competition (to maximize profits for distributive purposes) may deserve special attention.

53 Interestingly, similar proposals had also been made earlier in history in response to technological progress. For example, in 1964 a commission to then US President Johnson called for a minimum income as a right on the grounds that technological progress resulted in "a system of almost unlimited productivity capacity which requires progressively less human labour" (Donald G. Agger et al. 1964).

D. International cooperation

Whereas most of the policy areas discussed in the previous sections are domestic by nature, international cooperation plays a crucial role in ensuring that new technologies can indeed be developed and employed in a way that moves the world closer to sustainable development. In this context, international cooperation includes at least three different dimensions: addressing the cross-border aspects of new technologies, sharing of and learning from national experiences, and support for disadvantaged countries.

From a global perspective, there is a remarkable divide between studies focusing on developed countries and those on developing countries. While there are numerous empirical studies on the opportunities and challenges associated with the new technologies for the United States and Europe, very little work has been done regarding their consequences for low-income countries. Hence, there is a clear need to bridge this divide by encouraging research on the impact of a technological revolution on labour markets and income inequality in developing countries, in particular LDCs. In all countries, such research on the link between technology and labour markets needs to address not only job destruction, but also job-creating processes and how public policies can effectively shape these processes. For example, policies need to take into account how firms adopt new and advanced technologies to replace or to complement their workforce, and what are the consequences of these decisions for the demand for labour at various skill levels. The result of such research should be shared and discussed at the international level, as country or region-specific studies can be very informative for other countries as well.

Similarly, as countries continue to experiment with policies and regulations related to new technologies, there is scope at the international level to exchange lessons learned at the national level. Such exchange should involve not only Governments, but also scientists, business, unions and other stakeholders. The sharing can address not only the question of how policies and country-specific conditions influence the development and diffusion of new technologies, but they can also address the broader question of how these technologies contribute to the larger goal of achieving sustainable development. For example, international deliberations on automation and AI and their implications for sustainable development have started in the Multi-Stakeholder Forum on STI for the SDGs ("STI Forum"), mandated by the 2030 Agenda. These deliberations benefit from the dialogue between representatives of governments, science, business and civil society.[54]

A second dimension of international cooperation covers capacity building and technical cooperation on policy design and implementation on technology-related policies as well as on broader policies (such as education or social protection policies) that enable countries to better manage disruptions caused by technological progress. Ideally, such capacity building will be based on the experiences and lessons learned discussed at the appropriate international forums. In addition, many developing countries will also require support to build necessary infrastructure such as broadband, to ensure that they can participate in economic activities depending on new technologies. Existing mechanisms of international cooperation need also to take into account that a new technological revolution might lead to increased inequality between developed countries and more advanced developing countries on one side and disadvantaged groups of developing countries such as the LDCs on the other.

The third dimension of international cooperation addresses technology-induced changes to the nature of cross-border flows. One important aspect here is the commodification of information as a key economic driver. The question of information ownership and rights is not only important at the national level (see the discussion in section 6.A above), but also at the international level. Relatedly, questions of liability, privacy and security also involve international aspects. Hence, it might be worthwhile to explore the extent to which the international trading system under the WTO and other current international policy regimes are well suited to harness and manage the potential and challenges associated with new technologies. For example, the General Agreement of Trade in Services (GATS) under the WTO and most commitments for market liberalization in services stem from the early 1990s, before trade in data and information became important.

In addition to international trade, new technologies also have important implications on international tax cooperation. In many cases, profits associated with new technologies can easily be shifted across borders, even if economic activities are not shifted. This allows firms to reduce their tax liabilities, potentially cutting the amount of public resources available for redistribution as well as to promote new technologies, at a time where additional redistribution may be necessary to better manage the disruptive impact of new technologies.[55] Therefore, discussions and agreements on effective tax coordination in the appropriate forums (such as the United Nations Tax Cooperation Committee and the OECD) can play an important role in ensuring that global benefits accruing from new technologies can be effectively harnessed to ensure progress towards sustainable development in all countries.

Managing global intellectual property rights is also crucial. Granting intellectual property rights constitutes, and should always remain, a public policy action, one whose intention is to consistently stimulate—not restrict—private initiative in technological development. As argued in United Nations (2011), spurring technological development will require international public sector strategies which guarantee a commercial incentive substantial enough to enable private parties to use subsidies and public purchases of technology at reasonable cost in their research undertakings, while constraining monopolistic practices which restrict diffusion and further development. The new international regime should allow special

54 For a list of detailed conclusions and policy recommendations that emerged from the STI Forum, see https://sustainabledevelopment.un.org/unsystem/index.php?page=view&type=13&nr=2042&menu=23

55 See Frey et al. (2016), for example.

and differential access to new technology based on level of development.

E. Conclusion and the way forward

The widespread adoption of current technological breakthroughs, often labelled the fourth industrial revolution, will impact not only labour markets and income inequality, but will also lead to broader societal change. The nature of these impacts and changes, however, will remain unknown. Reducing the uncertainty of local, national and global impacts by further research and debate at the United Nations would contribute to better prepare countries to face these new challenges. Such research could also explore the linkages between the technology revolution and other key global trends, including demographic changes such as ageing and migration, climate change, and the overall need for transforming economies and societies to achieve sustainable development.

The public debate is largely driven by two opposing views around technological optimism and economic pessimism. While both views have merits, they are probably exaggerated and could risk deflecting attention from other pressing challenges. Technological optimism may tend to underestimate the organizational, managerial and infrastructure requirements needed for widespread deployment of new technologies in a way that does not generate major social disruption and political instability. Even on a purely technological level, the fundamental changes, for example, needed for AI to move towards creativity and approaching human intelligence on all dimensions could be far in the future. Simply extrapolating current trends of technological acceleration could be misleading, as not every temporarily accelerating growth path turns into exponential growth.

Similarly, economic pessimism towards new technologies may not only overestimate the depth and speed of technological deployment, it may also miss job creation effects and ignore economic barriers. For example, a country like Ethiopia faces formidable challenges to generate employment and structurally transform its economy as it progresses toward sustainable development. Adoption of old and new technologies will be part of Ethiopia's pathway to achieve the SDGs, so that estimates of 85 per cent of Ethiopians losing their jobs due to technology may be overstated and runs the risk of creating policy barriers to the adoption of new technologies, thereby harming development progress in the longer run.

Excessive optimism or pessimism on technologies and their socio-economic impact also translate into a passive policy stance, either because of a belief that problems would solve themselves (in the case of excessive optimism) or because they would become overwhelming and go beyond the capacity of decision-makers (in the case of excessive pessimism). However, rather than taking a passive wait-and-see approach, Governments as well as the United Nations can and should actively influence these processes. Given that technological progress is a key element to increasing productivity and a transition towards sustainable development, public policy has an important role to play in facilitating the adoption and diffusion of new technologies.

At the same time, proactive policies are also needed to better address the consequences of new technologies. If technology changes the nature of work and disrupts traditional social insurance systems, policies can reduce vulnerabilities by expanding social protection systems. If technology leads to less equal income distribution, policies are needed to redistribute income. National policies will have to be complemented by regional and global actions to address problems that are transnational in nature. Technological progress should not be used as an excuse for policy inaction, but rather as an incentive to find better solutions. A first step in this direction is to improve understanding of the technological revolution and its impacts at national, regional and global levels in order to accelerate the discussion about the policy options open to countries to benefit from new technologies and improve the management of negative side effects.

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