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Automation and the Future of Work

Scenarios and Policy Options

Joël Blit, Samantha St. Amand and Joanna Wajda

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Through its research, collaboration and publications, the Global Economy Program informs decision makers, fosters dialogue and debate on policy-relevant ideas and strengthens multilateral responses to the most pressing international governance issues.

Executive Summary

Driven by the exponential growth in computing power and the digitization of things, artificial intelligence (AI) and robotics are poised to transform the economy. While these technologies are likely to boost productivity and generate significant wealth, their potential impact on the labour market is concerning, with some estimates suggesting that nearly half of all existing jobs could be automated in the next two decades. What is almost certain is that these technologies will further increase inequality: workers with skills that are complementary to these new technologies will benefit, while those with skills that are substitutes will face dimming job prospects. The extent and speed of the transformation remains uncertain. This paper presents several possible scenarios for the future of work and draws on the Industrial Revolution to offer a historical perspective. It ends with a discussion of different policy options that could be deployed. Foremost, it highlights the urgent need for further international collaboration to broaden the tax base, both because tax avoidance is likely to become a bigger problem as wealth and income become increasingly concentrated and mobile and because of the likely need to expand the social safety net in the face of potentially massive and long-lasting disruptions.

Introduction

The next 20 years will see a technological revolution of a scale never witnessed before. Exponentially increasing computing power, AI, robotics, digitization, the Internet of Things (IoT) and blockchain technology will forever change the landscape of our planet. Many of the changes that they will bring will benefit humanity by, among other things, lowering the frequency and severity of road accidents, helping society grapple with an aging population, offering consumers more choice, increasing the efficiency of energy usage and facilitating distributed transactions and record keeping. Such changes are likely just the beginning, as human ingenuity will find myriad other applications for these technologies. As Ajay Agrawal, Joshua Gans and Avi Goldfarb (2018) point out, AI will make prediction cheap and, as a result, we are going to see it emerge in surprising and revolutionary places.

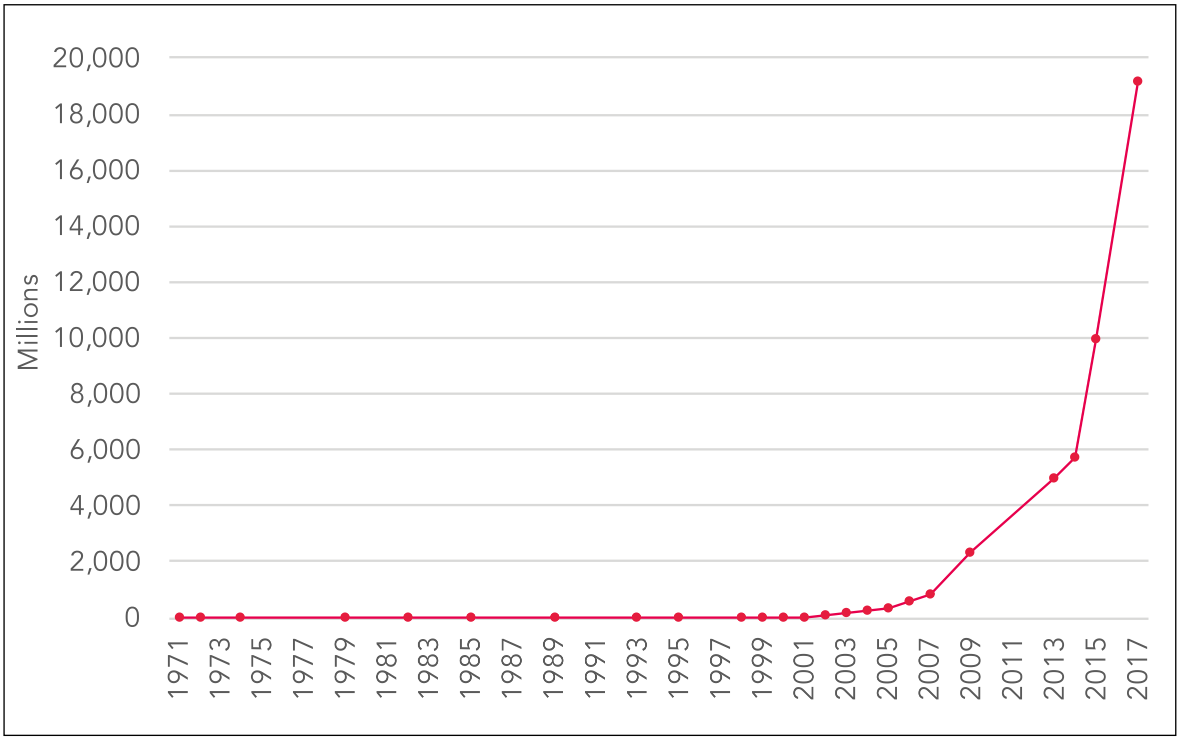
Despite all of these and other potential benefits, there is a significant risk that many people could be made worse off than their parents. These technologies, in particular AI and robotics, will be primarily labour-replacing and will reshape the labour market by changing the relative contributions of different factors of production. Most labour may become relatively less valuable, lowering the real wages and standard of living of workers.

To understand the likely impacts of AI and robotics, it is instructive to first consider the technological developments that have made AI and robotics practical solutions to so many real-world challenges. Chief among these is the giant leap in computing power. Since the 1960s, the number of transistors on an integrated circuit chip has roughly doubled every 18 months (see Figure 1), and this has occurred across numerous different semiconductor fabrication technologies. Other measures of computing power, including microprocessor clock speed and the number of floating point operations performed by the fastest supercomputer, have also exhibited exponential growth over this period.[1] As a result, there has been a dramatic decline in the cost of computing.

In no field is the impact of this growth in computational power more apparent than in AI. Many of the basic algorithms that underlie today's AI were developed decades ago, but, at that time, were not feasible solutions to real-world problems given the state of computing. Today, while algorithms have certainly improved, it is the giant leap in computing power that has made AI technology a feasible solution to so many problems. As recently as 2004, it was thought that computers could never challenge humans in pattern recognition tasks that could not easily be broken down into rules (Levy and Murnane 2004). Today, due to improved machine learning algorithms and more powerful processors, computers can analyze and write articles, sort images, retrieve unstructured information, recognize objects in order to safely drive cars and engage in complex verbal communication. They are increasingly able to perform not only routine tasks but also unstructured cognitive and creative tasks that it

1 Data available at https://ourworldindata.org/technological-progress.

Figure 1: Transistors per Microprocessor (1971–2017)



Data source: ourworldindata.org.

was once thought would forever remain the domain of humans. And, as computing power continues to expand,[2] it is difficult to find tasks that computers and robots will not one day be able to perform.

A second important factor in the increasing power of AI is digitization. As data, news, music, movies, books, maps, documents and numerous other information goods are created and stored in digital form, they are more readily usable by machines. Autonomous cars, for example, require detailed maps, and algorithms that write articles require a large database of previous news articles. Moreover, as service delivery itself becomes digitized, it becomes much easier to embed AI. It would be hard for a local bookstore to offer customers real-time book recommendations, but such capability is easily embedded in Amazon's online retail service. The digitization of such services further fuels the power of AI systems by generating more data with which to train future algorithms. Intel estimates that autonomous cars will generate roughly four terabytes of data per 1.5 hours of driving (Winter 2017), most of it by their cameras and light detection and ranging instruments that are used to measure distances. According to some reports, the total data created per year by any device could reach 163 zettabytes by 2025 (Reinsel, Gantz and Rydning 2017) or even 847 zettabytes by 2021 (Cisco 2018). The source of such data includes everything from data generated on social media, to data generated at the point of sale, to data generated by self-driving cars and the IoT.

Robotics has also made impressive leaps in the last few decades. Until recently, robots were inflexible machines that were very good at accomplishing a single, well-defined, repetitive task. But that too is changing with the newer generation of robots better able to handle non-routine jobs, thanks, in part, to the guidance of AI. Robots could soon start to perform tasks such as housekeeping, gardening, surgery and even construction.

The coming technological shift will bring significant benefits to the economy through

2 Whether computing power will continue to expand exponentially is debated. Thus far, whenever an existing semiconductor technology began slowing its rate of progress or even reaching a physical limit, new technologies and approaches emerged to keep computing power on an exponential growth path. While there remain many new materials and methods on the horizon (for example, tunnelling transistors and spintronic devices [Bourzac 2016] and quantum computing [Xie 2018]), it is uncertain whether they will underpin continued exponential growth.

increased productivity. Yet equally undeniable is the risk of major labour market disruptions. Governments must therefore start revising existing frameworks and institutions, as well as building new ones, to ensure they have maximum bandwidth and flexibility in future policy. While it may be too early to implement specific policy responses, now is the time to start examining policy options and developing a tool kit to have ready in the event of major disruptions.

In the section that follows, several possible scenarios for employment and inequality are presented and the most likely outcomes are discussed. The third section then examines policy preparedness and policy options. The importance of maintaining a broad and sustainable tax base to allow for flexibility in the policy response is emphasized. Several other policy areas that will be relevant for addressing the direct impacts of these technologies on labour markets are then highlighted, including the presence of a well-designed social safety net and a modern education policy. It should be noted that this paper is not a detailed analysis of either the issues or potential policy responses, but rather an overview and a call for further research and analysis.

Scenarios for Employment and Distributional Consequences

The biggest benefit that these technologies will bring to the economy is increased productivity. By deploying AI and robotics, humanity will, quite simply, be able to do more with less. Seen this way, the technological transformation that is under way is just the latest incarnation of the race to improve our standard of living through technology. But this view fundamentally underestimates the potential disruptive impacts of these technologies on society and how quickly these impacts are likely to be felt. While these technologies may make society richer overall, unless the right governance structures are put in place, certain segments of society are likely to receive most of the benefits while others suffer most of the costs. That is, while in the past economists may have viewed technological change as being largely factor-neutral and, thus, a tide that lifts all boats, this will not be true with the current revolution, which is certain to benefit some factors of production while harming others.

The fact that technological change can result in winners and losers is now well understood in the context of the technological change brought about by information and communication technology (ICT). These technologies have, on the whole, been complementary to skilled labour (for example, professionals using computers became more productive) while displacing many unskilled jobs (for example, switchboard operators). This skill-biased technical change increased (decreased) the relative wages of higher (lower) skilled workers and is thought to be the main reason why, over the last several decades, inequality has been on the rise (see, for example, Krueger 1993; Autor, Katz and Kearney 2006; Acemoglu 2002).

While the ICT experience provides a parallel for thinking about the potential impacts of the oncoming revolution, AI and robotics will have a different and more profound impact on the labour force, in that these technologies may replace entire swathes of the workforce, affecting not only routine tasks but also non-routine and non-repetitive tasks that were previously thought to not be automatable. As in the case of ICT, different factors of production will be affected differently, depending on whether the new technologies are a complement to, or a substitute for, that factor. Complementary factors of production, such as entrepreneurial ideas and skills, will experience a substantial increase to their marginal productivity and hence to their earnings. These technologies make it much easier and less expensive for entrepreneurs to implement their vision and serve millions (and even billions) of customers at minimal cost.

Some recent technological success stories bear this out. YouTube was founded in 2005 and bought by Google just over a year later for US$1.65 billion (Google Inc. 2006). The founders were able to reach millions of viewers quickly and with few employees. A little over a year after its founding, YouTube was visited by 20 million unique users per month and was streaming 100 million videos per day, and with only around 30 employees (*USA Today* 2006). But the case of YouTube is not unique. Instagram was founded in 2010. Less than two years later, the company of only 13 employees was acquired by Facebook for US$1 billion (Ford 2015, 175). This narrative was repeated in 2014 when

Facebook purchased WhatsApp, a company with a workforce of 55 individuals, for US$19 billion (ibid.).

If the good news is that it will be easier for entrepreneurs to leverage their idea and generate wealth, the bad news is that the latest automation technologies appear to be less labour-augmenting and more labour-displacing (Autor and Salomons 2018). The type of labour that can be replaced by AI and robotics is likely to become extinct because workers will be competing with a substitute factor of production whose marginal cost is close to zero (once the algorithm has been developed, deploying an AI system is relatively inexpensive). Unlike ICT, AI technologies are substitutes to labour in a much broader set of jobs and tasks, across most of the income distribution. Moreover, as entire sectors shed jobs, the decreased demand for labour could result in an economy-wide reduction in wages (even in sectors not directly affected).

This paper discusses three broad scenarios for employment: a pessimistic scenario that emphasizes job losses from automation; an optimistic scenario that emphasizes job creation from technological disruptions; and a skeptical scenario that considers both the negative and positive implications of technology but emphasizes the potentially long and difficult transition period involved.

Pessimistic Scenario — Emphasizes Job Losses from Automation

Just how big of an impact could AI and robotics have on employment? Carl Benedikt Frey and Michael A. Osborne (2017) estimate that 47 percent of US jobs are susceptible to being replaced in the next 10 to 20 years, a *pessimistic scenario* indeed. A more recent analysis by Melanie Arntz, Terry Gregory and Ulrich Zierahn (2016) uses a task-based (instead of occupation-based) approach, and while they find that few occupations are entirely automatable, most occupations have a significant share of their component tasks that are automatable. Thus, while an occupation where half its component tasks are automatable will not cease to exist, employment in that occupation could be halved if half the tasks would be performed by machines.[3] It seems that the two approaches could tell a not-too-different story with respect to potential losses of jobs due to automation.

Optimistic Scenario — Emphasizes Productivity Gains and Job Creation

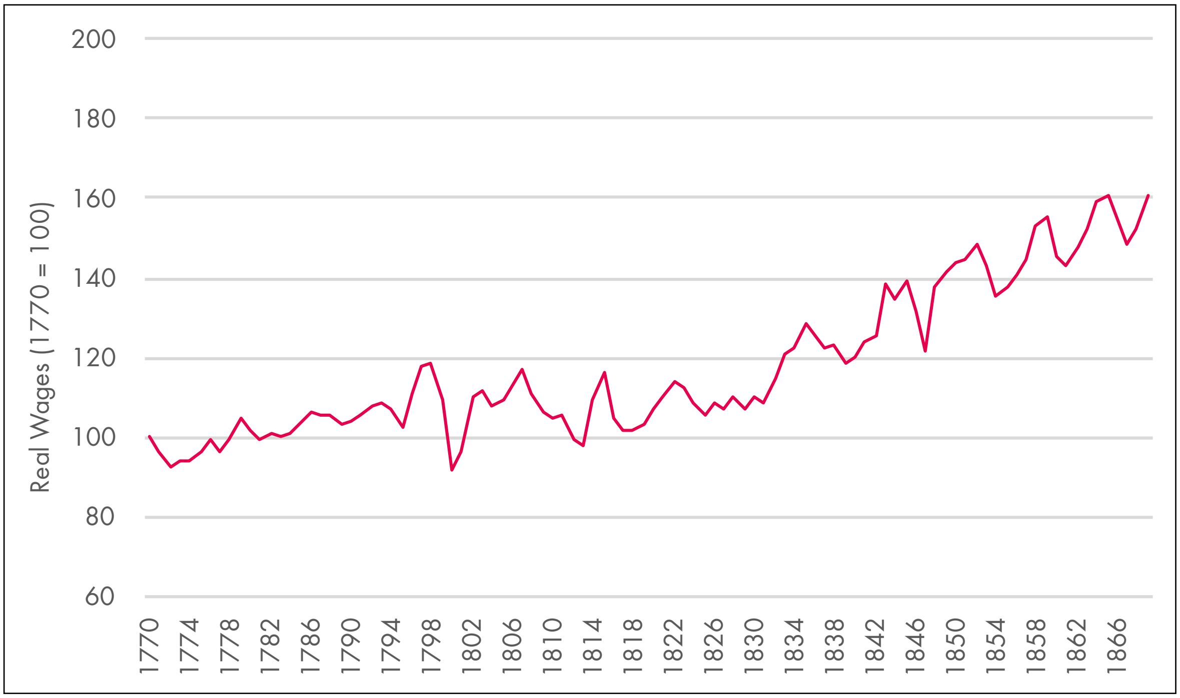
The default position of many economists seems to be that while technological disruption may destroy some jobs, it will also spawn new industries and create new jobs. Moreover, because of our limited capacity to foresee new technological possibilities and how they can be harnessed to create valuable products and services, we may systematically underestimate the potential number and magnitude of such new industries. While this has been true in the past, and will probably also be true for the current revolution, economists may be overly sanguine about short- and middle-term employment prospects.

New industries are indeed emerging, but if the social media platforms and digital services discussed above are any indication, it may not be realistic to expect new industries to generate jobs quick enough to offset expected job losses. Together, YouTube, Instagram and WhatsApp employed fewer than a hundred individuals at the time of their acquisition. Even if we account for the number of jobs that such platforms have indirectly created, it is not enough to make up for potentially large job losses in more traditional sectors. For example, while YouTube's biggest star made an estimated US$16.5 million in 2017 (Berg 2017), only a small group of content creators consistently generate enough income to make a living (Bärtl 2018). Moreover, this type of employment is generally part time and precarious (YouTube fads change quickly) and, therefore, is not a solution to the oncoming disruption to labour markets.

A second reason why one could be optimistic is that automation increases productivity, which, through competition, should reduce prices. Thus, even if nominal wages are stagnant or even declining due to a decreased demand for labour, workers could be better off if prices drop significantly, thereby increasing real wages.

3 Although the increased productivity of that occupation could result in increased demand for its services. The number of jobs lost would thus depend on the price elasticity of demand for the service (and there could even be a net gain in jobs).

Figure 2: Average Real Wages in England during the Industrial Revolution (1770–1869)



Data source: Allen (2007).

Skeptical Scenario

History may be a useful, albeit imperfect, guide in weighing the likelihood of the optimistic scenario bearing out. The Industrial Revolution is widely seen as having been hugely beneficial to humankind, raising productivity, wages and the standard of living; however, often overlooked is the fact that it took half a century for workers to experience any significant benefit (Allen 2007; 2009). As shown in Figure 2, British real wages remained largely stagnant for 50 years following the revolution. This suggests that amid a technological revolution that is widely seen to have created tremendous wealth, large swathes of society would not have seen any benefit to their real earnings prospects over their entire working life. As with any large disruption, some sectors of society would have seen a decline in their real wages, if not unemployment. Seen in this light, it is possible to sympathize with the luddites' futile attacks on weaving machinery. The fact that machines were eventually going to make everyone better off would have been a small consolation to a weaver who had just entered the workforce circa 1770.

There is, thus, good reason to be skeptical of the optimistic scenario, especially if we are concerned, not just about the long run, but also about the welfare of workers in the intervening decades. Particularly so, given that AI, digitization and robotics are likely to engender a revolution with an impact on labour markets that will dwarf that of the Industrial Revolution.

There are equally good reasons to be skeptical of the pessimistic scenario. The potential loss of roughly half of existing US jobs in the next 10 to 20 years is certainly cause for alarm, and governments should make plans for dealing with such a scenario should it bear out. But just because half of all jobs could be automated does not mean they will be. First, it is not clear that automation is the cost-effective choice in many sectors. For many tasks, developing the systems to automate them could be expensive and firms would optimally choose to forego that investment (at least in the near future). Second, regulations often move more slowly than technology, effectively putting a brake on their deployment (as is apparent in the case of autonomous vehicles). Third, organizations, especially large ones that employ many people, often struggle to change their operations even when a more cost-effective alternative exists. Organizations, and society more generally, are resistant to change.

A more realistic scenario might be one where technology puts pressure on many existing jobs but societal factors slow its impact on the labour force. Many jobs could still be lost, but perhaps not half of them, and automation might happen over a longer time frame than expected. Estimating exactly how many jobs will be lost and how quickly is a challenging proposition; here again, historical data may offer some predictions. Daron Acemoglu and Pascual Restrepo (2017) analyze the effect of industrial robots on the US labour market from 1990 to 2007 and find that one more robot per thousand workers reduces the employment to population ratio by between 0.18 and 0.34 percentage points and wages by 0.25 to 0.5 percent. For Germany, Wolfgang Dauth et al. (2017) find that for the period 1994–2014, an increase in the number of robots did not have a significant effect on total employment, but it did result in a 23 percent decline in the number of manufacturing jobs. The authors also find significant distributional impacts: high-skilled workers earned more (possibly due to having complementary skills) while low- and medium-skilled workers earned less (ibid.). Overall, the historical evidence does suggest that since the 1990s the increased use of robots in advanced economies has had distributional — if not total — effects on wages and employment.

The trend in increasing inequality, presumably due to the ICT revolution, offers further evidence that workers may face challenges ahead. The middle class has seen decades of stagnant real wages (Mishel, Gould and Bivens 2015; Uguccioni, Sharpe and Murray 2016) and the concern is that earnings prospects are likely to get worse for the median family over the coming decades. Unlike the Industrial Revolution, AI and robotics will affect not just a few industries or a small subset of occupations, but the majority of them. These technologies are also being adopted much faster than machines were in the second half of the eighteenth century. We might, thus, expect more serious effects on labour markets, from severe unemployment to reductions in real wages, and an associated decline in the standard of living for the median family.

Distributional Consequences

In the introduction to their highly influential book, *The Second Machine Age: Work, Progress and Prosperity in a Time of Brilliant Technologies,* Erik Brynjolfsson and Andrew McAfee (2014) write that

> as computers get more powerful, companies have less need for some kinds of workers. Technological progress is going to leave behind some people, perhaps even a lot of people, as it races ahead. As we'll demonstrate, there's never been a better time to be a worker with special skills or the right education, because these people can use technology to create and capture value. However, there's never been a worse time to be a worker with only "ordinary" skills and abilities to offer, because computers, robots, and other digital technologies are acquiring these skills and abilities at an extraordinary rate.

Workers with skills that are complementary to these technologies will indeed experience tremendous growth to their productivity and wages, while workers whose skills are substitutable with these technologies will either see declines in their wages (until their wages are so low that they can compete with the machines) or will face unemployment. For this reason, we could be on the cusp of an era with levels of inequality that are unparalleled in modern times.

This increasing inequality will not only result in large swathes of society finding themselves to be worse off than their parents, it could also undermine the entire economic system. Given that individuals who are lower down in the income distribution consume a greater portion of their income than those at the top, any transfer of income from the bottom to the top will result in less total consumption. In the extreme, one could envision a downward demand spiral where reduced consumption leads to further employment losses, which would further reduce consumption. Large levels of inequality also pose a risk to our political system, specifically to democracy. Individuals who have become so rich that they are able to provide their own health, education and security services, will stop seeing the need for government to provide such public goods. And they may wield their tremendous influence to protect or even enhance their position of privilege.

As shown by Jeffrey D. Sachs, Seth G. Benzell and Guillermo LaGarda (2015), automation could not only result in a temporary increase in output, but a permanent decrease in the standard of living (by lowering the demand for labour and hence wages). If large returns to automation accrue to a narrow portion of society (those who own the technology), society as a whole could become worse off. However, in their model, immiserization can be overcome through government distributive policies. As David H. Autor (2015, 8) argues, "the fundamental threat is not technology per se but misgovernance; an appropriate capital tax will render the technological advance broadly welfare-improving."

AI and robotics will generate tremendous wealth. For that reason, and because attempts to contain innovation have historically failed, there should not be attempts to limit the adoption of these technologies. In fact, their adoption should be encouraged. But governments have an important role to play in ensuring that the benefits accrue broadly and are sustainable. They can also start preparing workers for the labour market that lies on the horizon, ensuring workers have skills that are complementary to and not substitutes of these technologies. Given the looming uncertainty, governments should now start building the frameworks and institutions that will afford them maximum flexibility in future policy. Perhaps most important among these is establishing and maintaining a broad tax base. The section that follows discusses this and several other possible policy considerations and avenues requiring further research.

Policy Considerations

Institutional structures play an important role in determining the rate of technological change and the implications of these changes for society. Governments need to play a role both in ensuring that the maximum benefit is derived from these emerging technologies and in mitigating the consequences of technology moving faster than the labour force is able to respond.

The exact nature of the coming changes is hard to predict, creating significant uncertainty about what policy responses will be appropriate or necessary to adjust to the changing nature of production. The implications of these structural changes will also likely differ by country depending on, among other factors, the industrial structure, demographics and social cohesion. To be able to adapt to these changes, governments will need to preserve policy flexibility.

This paper proposes several policy areas that need to be studied more closely, focusing specifically on those that have direct implications for labour markets. The objective is not to suggest specific policies that should be implemented, but to propose policy alternatives for discussion and further examination. The future, although uncertain, is sure to be tumultuous, and only by having a ready tool kit of policy options can governments hope to react quickly and effectively to whichever scenario unfolds.

Maintaining a Broad Tax Base

The most pressing policy issue is securing a broad and sustainable tax base to ensure that governments maintain their ability to react to changes in the economy. Current taxation arrangements may be insufficient to achieve a broad and sustainable tax base. An accelerating rate of productive capital (for example, labour, physical capital and, most significantly, intellectual capital) mobility, the increasing concentration of income and wealth and the changing nature of production all pose challenges for taxing profits, capital gains and incomes. The acceleration of globalization in the 1990s enabled multinational enterprises to strategically allocate operations and financing activities to avoid taxes. Indeed, increased global capital mobility has created incentives for firms to allocate investment in jurisdictions with lower taxation (see, for example, Skeie 2016). Technological advancements facilitated the rising mobility of productive capital. ICT made it much easier for offices in different locations around the world to communicate quickly and efficiently, and financial technologies continue to improve the ability to transfer funds across the world at a lower cost and higher speed than ever before.

These issues are, of course, not new, but they may soon reach an entirely new scale. The coming technological revolution will increase governments' need to generate revenue to mitigate the massive displacement of workers while reducing their ability to do so. If automation is labour-displacing, income and payroll tax collection will decrease, requiring a larger share of taxes to be collected from other sources.

Intangible assets, such as data, algorithms and technological know-how, will become increasingly important sources of profit generation as a larger share of the economy becomes digitized. Investment in intangible capital is already larger than investment in tangible capital (Haskel and Westlake 2017) and as Dick Bryan, Michael Rafferty and Duncan Wigan (2017) explain, intangible capital can lead a "double life," exploiting taxation and regulatory arbitrage by being located in multiple jurisdictions. For this reason, intangible assets have been disproportionately linked to profit shifting through offshore financial centers (see, for example, Grubert 2003; 2012; Riedel 2014). In an economy where many services are produced by data and algorithms can reside abroad, how much power of taxation will individual governments have? When the most important factor of production shifts from labour to capital and intangible assets, which are both more mobile and difficult to tax, effective taxation will require increased cross-national collaboration.

To be sure, international tax policy cooperation has strengthened significantly over the past few years. The Common Reporting Standard for the Automatic Exchange of Information (AEOI) is a crucial element of these efforts; open exchange of tax information is needed to identify tax evasion. The commitment of the G7 countries to implementing these standards is commendable. Using political leverage to encourage allied countries to commit to the AEOI standard could help fill remaining gaps in this system. The Organisation for Economic Co-operation and Development (OECD)/Group of Twenty (G20) Project on Base Erosion and Profit Shifting (BEPS) complements these efforts by laying out a package of measures aimed at improving the consistency of international tax cooperation and ensuring that taxable profits are allocated according to the location of value creation and economic activity.

But despite substantial action on international tax policy cooperation, several issues remain unresolved. Critics argue that the BEPS approach to addressing transfer pricing through the "arm's length principle" will not eliminate profit shifting (see, for example, Collier and Andrus 2017). Despite devoting significant attention to extracting tax from the profits generated from intangible assets, the BEPS framework makes little-to-no progress on this issue (Brauner 2016). Several alternative approaches to addressing profit shifting have been proposed (see, for example, Auerbach et al. 2017; Independent Commission for Reform of International Corporate Taxation 2018); each approach has its own flaws. What is clear is that continued efforts toward finding a collaborative solution will require ingenuity in accounting and political cooperation. The urgency of finding the appropriate way to tax equitably and broadly will only grow with the increased concentration of wealth.

Education and Skills Training

Technological change implies that many skills in demand today will not be in demand tomorrow. If displaced workers could upgrade their skills quickly enough, we would not experience the massive levels of unemployment that some are predicting (although income inequality could still spike). A fundamental challenge, then, is how to design an education and training system that helps the labour force keep pace with, or perhaps even stay ahead of, technological change. The flexibility required of the labour force demands a cultural shift, but there is also a role for government in ensuring the primary and secondary school system imparts foundational technology skills and in setting up incentives to encourage effective retraining and lifelong learning.

A faster rate of technological change means that education and training must be adaptable and responsive. The current education system, which emphasizes front-loading of learning and skills training, will need to be redesigned to teach skills that are more adaptable and will need to be complemented with lifelong learning so workers stay current. Upfront education and skills training should be broad and focus on adaptable skills such as reading, writing, problem solving, critical reasoning, creative thinking, social skills and emotional intelligence. Applied skills, on the other hand, should be spread out over the course of the working life to encourage flexibility in response to changes in labour demand and the development of new technologies. Self-directed and on-the-job learning and training will play an ever-more-important role, and for workers who get pushed out of the labour force, government retraining programs could be crucial.

Such changes may, at best, keep workers from falling too far behind the accelerating technological change, and the only effective solution may in fact be to ensure that the labour force stays ahead of technology. That, of course, requires predicting the future, which, at the best of times, is a risky endeavour. However, an understanding of the technologies and economic theory and a historical perspective can inform our predictions of the skills that are likely to be in demand in the future. While, on the one hand, economic theory cautions against investing in skills for which AI and robotics are substitutes, on the other hand, it advises that one should seek to acquire the skills that are indispensable complements to factors of production that will become cheap and plentiful (such as data and algorithms). Thus, it is a fairly safe bet that data scientists who can interpret data, or entrepreneurs with ideas that can be implemented by leveraging data and algorithms, will both have a bright future.

Most jobs will evolve to require significant interaction with machines. Therefore, it is important that the future labour force is comfortable with machines and can communicate effectively with them. Today, that means that more graduates should possess computer programming skills, regardless of whether their degree is in engineering or in the arts. Understanding how computers operate, their strengths and their limitations, will be an important asset. An important lesson from the world of freestyle chess, where people and computers work together as a team, is that a mediocre human player who knows how to work collaboratively with a machine can usually beat both a grandmaster chess champion with little knowledge of computers and the most advanced machine by itself (Kasparov 2010). Consequently, there may always be an important role for humans who know how to work with computers.

In the future, wages (and employment prospects) are likely to depend on how well a worker complements computers and robots. Humans will likely retain an advantage in skills such as idea generation, creativity, complex communications, empathy, unstructured problem solving and broad pattern recognition. On the latter, because so far computers are good at pattern recognition and problem solving only for narrow applications, perhaps AI will foster a resurgence of the renaissance ideal of a person who can draw on insights from many disciplines and fields to solve complex problems.

Fostering Entrepreneurship

As alluded to in the earlier discussion, entrepreneurial skills (the ability to recognize opportunities, think creatively, problem solve and execute) are not only skills that machines cannot replicate, they are skills that are highly complementary with machines and therefore likely to be well compensated. Moreover, workers with an entrepreneurial mindset are also more resilient. When faced with unemployment, they are more likely to find or create new opportunities, perhaps leveraging the low fixed cost of digital platforms to offer a niche service. Thus, our education system should both promote entrepreneurial values and teach entrepreneurial skills. Students should be taught to be curious, to welcome new challenges as opportunities and to embrace change.

The second, and perhaps more important reason for creating an entrepreneurial labour force, is that entrepreneurship is the engine of the economy. As old industries retrench, or disappear altogether, entrepreneurs are the individuals who will create the new industries where our future labour force will be employed. True, many entrepreneurs may create few jobs (as was the case with YouTube, Instagram and WhatsApp), but they will create some, if only for themselves. And in the long run, and assuming the right redistributive policies are in place, a groundswell of entrepreneurial activity should increase everyone's standard of living.

Social Safety Net and Worker Protection

Automation will disrupt the labour market, destroying some jobs while creating others. If jobs are destroyed more quickly than they are created, as the nature of the technologies suggests will be the case, at least initially, a strong social safety net will be needed to support workers over the medium term (which, as we have seen, could last several generations). We must consider whether our welfare systems would have the capacity to handle a massive increase in unemployment as the economy undergoes this transition.

The nature of employment is also changing. Perhaps due to the more uncertain environment, firms are increasingly relying on part-time and contract workers (see, for example, Cassidy and Parsons 2017; Valletta, Bengali and van der List 2018). More workers are also engaging in "gig" work; in the United States and parts of Europe, as many as

20 to 30 percent of the working-age population is engaging in independent work, with close to one-third doing so out of necessity, and about half of those doing so to supplement their primary income (Manyika et al. 2016). Of all independent workers, 15 percent is facilitated through digital platforms. While those that choose independent work willingly report higher satisfaction than those that choose it out of necessity, it has been argued that the rise of digital platforms is determined more by a surplus of labour and an imbalance of power in the employer-employee relationship than by the willingness of workers to seek out contingent work made possible by these digital technologies (Stanford 2017). However, there remains too little data to understand the nature and implications of this type of employment (see, for example, Abraham et al. 2017).

These types of work arrangements may lack the protection and benefits of traditional employer-employee relationships, such as employment security, a stable income, stable hours of work, paid vacation, health and disability insurance and so on. Independent work may not be protected by existing labour laws, such as minimum wage and minimum hours of work, and may not be subject to the same labour dispute processes as employer-employee relations. Policy makers must start considering how the social safety net and labour standards can be rethought to apply to all types of workers, including contract workers and the self-employed.

In this new labour market, workers may find less consistent employment or may experience more frequent gaps in their work history due to skills training and retraining. One way to adapt the social safety net to fit these new circumstances is to increase the flexibility of eligibility tests for employment insurance and retraining programs. More significant changes to the social safety infrastructure may be warranted to address the extent of the changes in the labour market. A portable social security system — first proposed by Steven Hill (2015) at the New America Foundation — is one such option. In this system, every worker would have a social security account and businesses would contribute to this account according to wages paid (regardless of the type of contract or task performed). These accounts could help fund social security programs, such as employment, health, disability and life insurance, and, potentially, other protections currently afforded by employers to full-time employees, such as vacation pay, skills training allowance or child care. Another policy option is some form of a universal basic income, which, beyond ensuring the livelihood of individuals, would also abate the risk of a downward demand spiral. Such a system can be designed in many ways, and the basic income experiments being conducted around the world, for example, in Finland and Ontario, aim to identify program designs that work (and do not work) in various economic contexts (*The Economist* 2018; Younglai 2017).

International labour standards will also become more important as employer-employee relationships increasingly transcend borders in the digital economy. The International Labour Organization (ILO) is already engaged on issues related to the coming shifts from automation, including informal work, declining share of labour in production, growing inequality and youth unemployment. The G7 and G20 can renew support and increase funding to the ILO to help transform the institution into a champion for the rights of workers in the twenty-first century.

Competition Policy

Technology is changing the shape of industries. As discussed in the previous section, intangible assets are becoming an increasing source of profit generation and there is the risk that these assets will become concentrated among a handful of major tech firms. Many high-tech sectors are natural monopolies for at least three main reasons. First, there are high barriers to entry in the form of data and knowledge requirements, and these are exacerbated by the proliferation of intellectual property (Ciuriak 2017). Second, the digital nature of many goods and services implies large fixed costs but negligible variable costs, leading to a winner-takes-all outcome. Third, platforms, whether operating systems, standards or social networks, exhibit network effects and so the biggest tend to get bigger. Monopolies not only tend to impose higher prices for consumers and generate deadweight losses for society, but they can also have adverse effects on the labour market. Industry concentration has been linked to a declining labour share of income (Autor et al. 2017).

More research is needed to understand the future industrial landscape and develop possible policy responses. News media have recently reported on large tech firms acquiring smaller competitors, suppliers and even firms in apparently different industries (for example, Amazon's acquisition of Whole Foods). If monopolistic tech firms are becoming one of the largest employers worldwide, the implications of this industrial composition for the workforce need to be better identified. How much bargaining power will workers with sector-specific skills have if there is only one potential employer in their sector? Having competing firms at different stages of the lifecycle may also be necessary to encourage innovation and a dynamic labour market. Breaking up the electronic platforms through which so much of our economy will flow may need to be considered in the years to come, similar to the telecoms that were broken up in the early 1980s.

Data Policy

Data is a crucial component of the digital economy. Without it, AI algorithms cannot function and firms cannot inform their decisions. The hundreds of zettabytes of data that will be generated in the future by online platforms and devices connected to the Internet will provide ample fodder for firms to develop tailored products and services.

But expanding data collection needs to happen in tandem with the development of data governance standards (see Medhora et al. 2018). A first step is deciding who owns personal data — the individuals that generate it or the firms that collect it. Deciding what rights individuals have to their data will dictate whether their explicit consent is needed to access, collect and distribute their data and the level of information that must be provided about the intended use. If data is now the most important asset, antitrust regulators must consider how to regulate the firms that control it. The dominance of firms such as Amazon, Alphabet and Facebook, and the tremendous power that such data hoards afford (including the power to limit competition), has prompted some to call for the breakup of such firms. A number of other solutions have also been proposed, from giving more control over data to those that supply it, to mandatory data sharing for crucial classes of data (subject to privacy concerns).

Data is not only a fuel for new sectors; it can also be a tool for public good. Governments around the world have a responsibility to ensure that public information, scientific information and public domain information are accessible and free. Fundamentally, because data is central to the digital economy and a human rights issue, governments must put in place the structures that ensure it is used fairly and for the benefit of all. In addition, issues around privacy, ethics and security must all be addressed.

Conclusion

The rapid growth and adoption of AI and robotics will have uncertain, but potentially serious and long-lasting consequences on employment, wages and the income distribution. It is vital that countries be prepared with a menu of possible policy options to address each of the many potential scenarios as they arise. These can include reforms to education systems, fostering of entrepreneurship, strengthening of social safety nets and competition policy. Most pressing is the need for continued international cooperation to develop international institutions and frameworks that ensure fair and broad taxation, because the coming technological revolution will increase governments' need to generate revenue while reducing their ability to do so.

International tax policy is by its very nature an issue that needs to be addressed multilaterally. The G7 and G20 are uniquely well placed to further advance this agenda. The significant threat posed by the oncoming technological revolution should be the catalyst that focuses efforts on upgrading international tax frameworks and institutions. Delaying such cooperation could prove disastrous, as states may find it impossible to implement such policies if wealth becomes entrenched in the hands of the few.

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