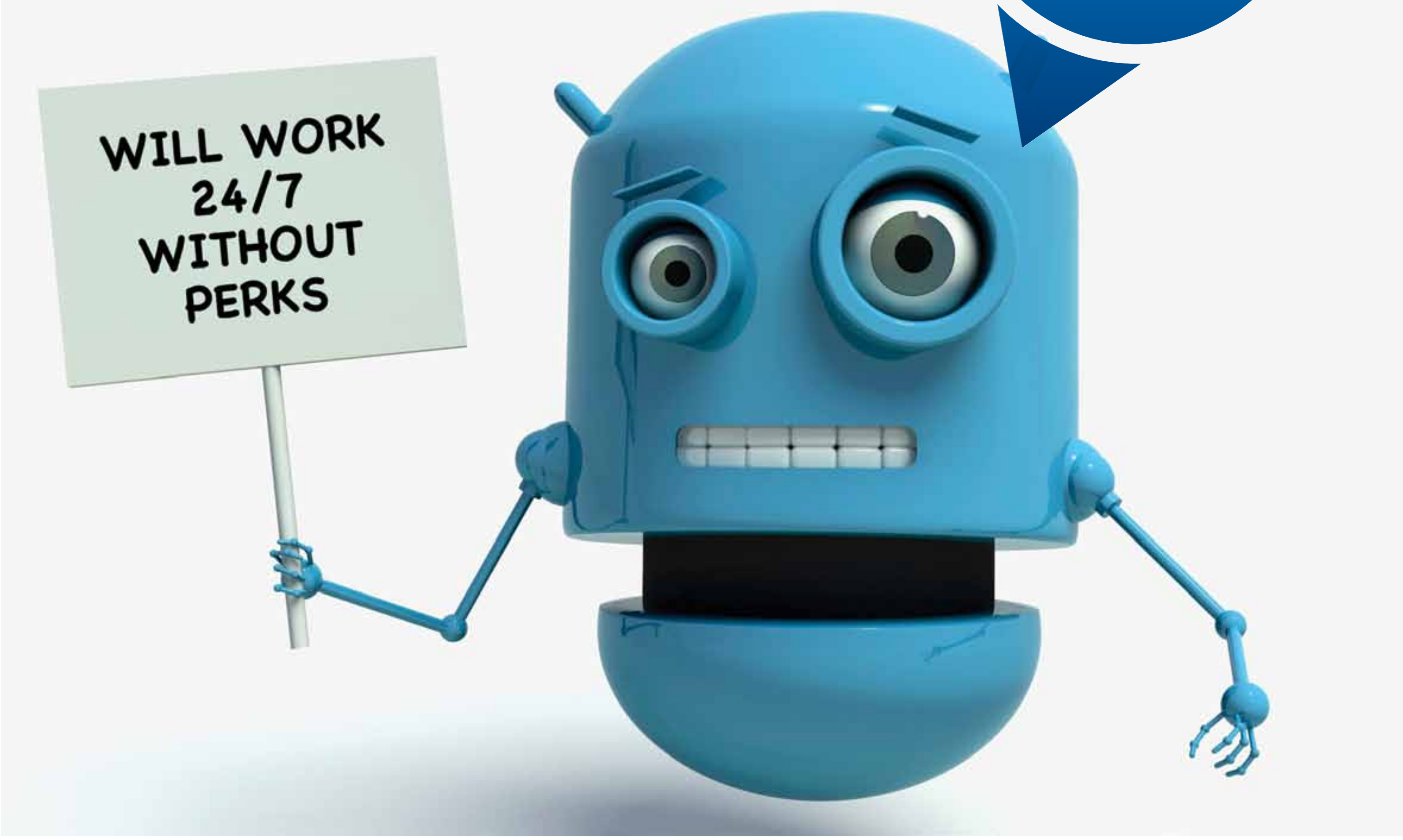

TECHNOLOGY AT WORK

The Future of Innovation and Employment

Citi GPS: Global Perspectives & Solutions

February 2015

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With contributions from Citi Research

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TECHNOLOGY AT WORK

The Future of Innovation and Employment

It is a pleasure to introduce *Technology at Work: The Future of Innovation and Employment.* This report is the second in a long-term series of Citi GPS reports co-produced by Citi and the Oxford Martin School at the University of Oxford in order to explore some of the most pressing global challenges of the 21st century. This report follows the launch report in the Citi Oxford Martin School collaboration that was entitled *Future Opportunities, Future Shocks: Key Trends Shaping the Global Economy and Society* which outlined not just the key trends that we see shaping global markets, society and technology but also the potential risks and shocks to the global system.

In this new report, Oxford Martin School academics Dr. Carl Benedikt Frey and Associate Professor Michael Osborne examine a pressing subject increasingly in the headlines: the changing nature of innovation and work, and the associated implications for the future of employment and society more widely. We are also very pleased to say that this report marks the launch of the Oxford Martin Programme on Technology and Employment, a long-term programme of research at the University of Oxford supported by Citi that will focus on many of the areas covered in this report.

The digital age is set to cause more upheaval than previous technological revolutions because change is happening faster than ever before and is fundamentally altering the way we live and work. Technology is now enabling not just the automation of repetitive tasks but also cognitive tasks involving subtle and non-routine judgment. Through robotics, big data, the digitisation of industries and the Internet of Things the nature of occupations and whole industries is changing and also the dynamics of economic growth. The economic benefits of recent technological developments are not being widely shared. Productivity has increased globally but real median wages have stagnated in many OECD countries leading to significant declines in labour's share of GDP.

Writing in partnership with Citi analysts, Carl Frey and Michael Osborne comprehensively assess the extent of automation and its effects on the labour market across industries and countries. Crucially, in addition to analysing the risks and opportunities of the digital era, the authors propose pathways and strategies that can help governments and societies adapt successfully.

We hope that you enjoy this Citi GPS report. Going forward, further reports will share the results of the exciting collaboration between Citi and the Oxford Martin School.

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Global Head of Research
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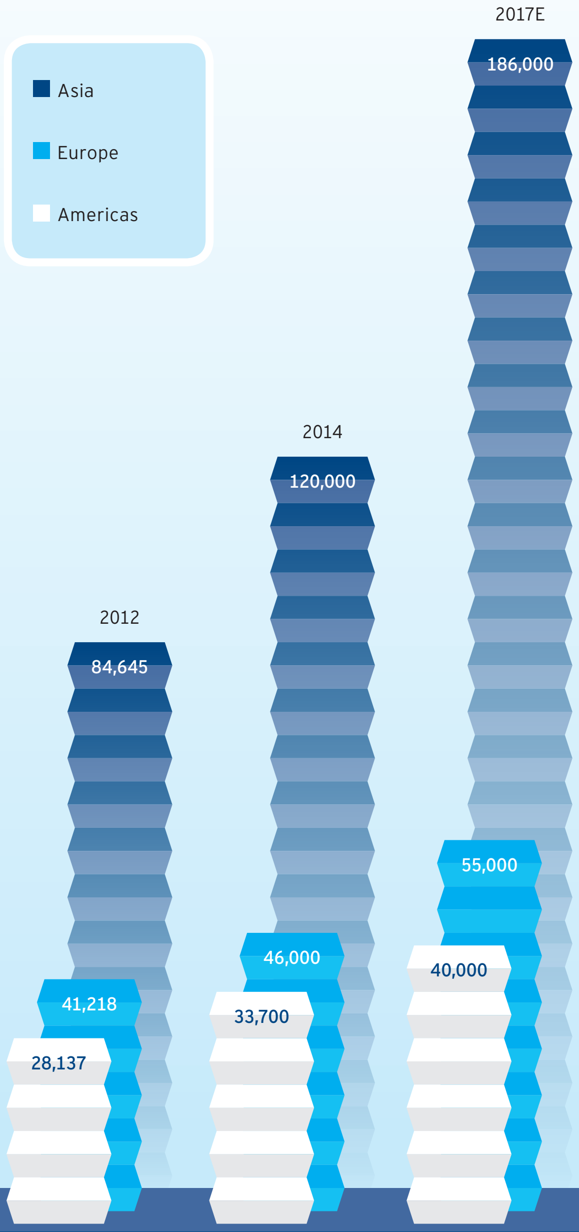
The Changing Nature of Innovation and Work

Addressing inequality brought on by technological change

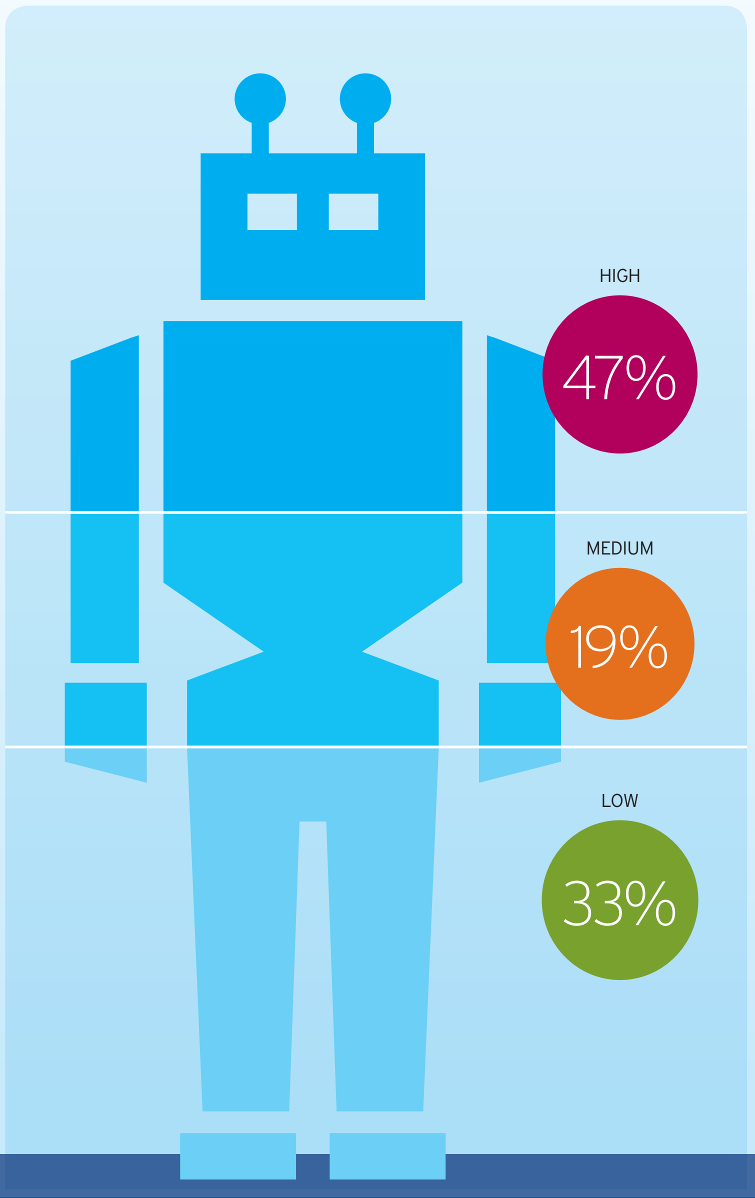
ANNUAL SUPPLY OF INDUSTRIAL ROBOTS BY REGION

Source: IFR World Robotics 2014



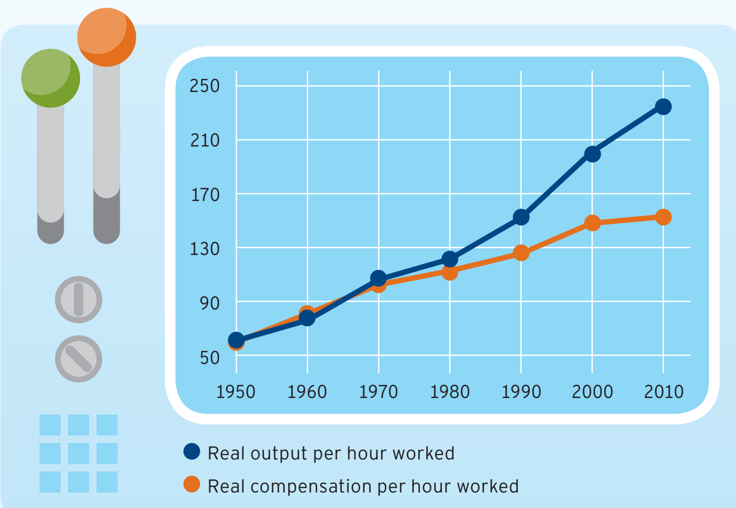
PERCENT OF US JOBS AT RISK DUE TO COMPUTERISATION

Source: Frey & Osborne (2013)



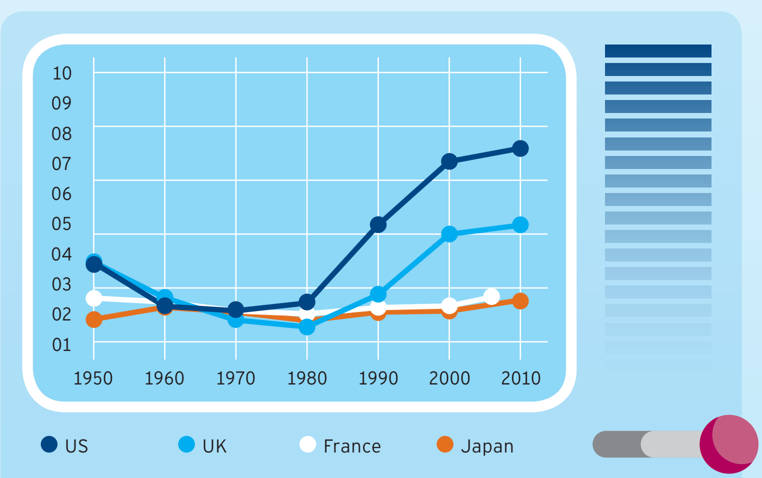
PRODUCTIVITY HAS INCREASED FASTER THAN WAGES IN THE US

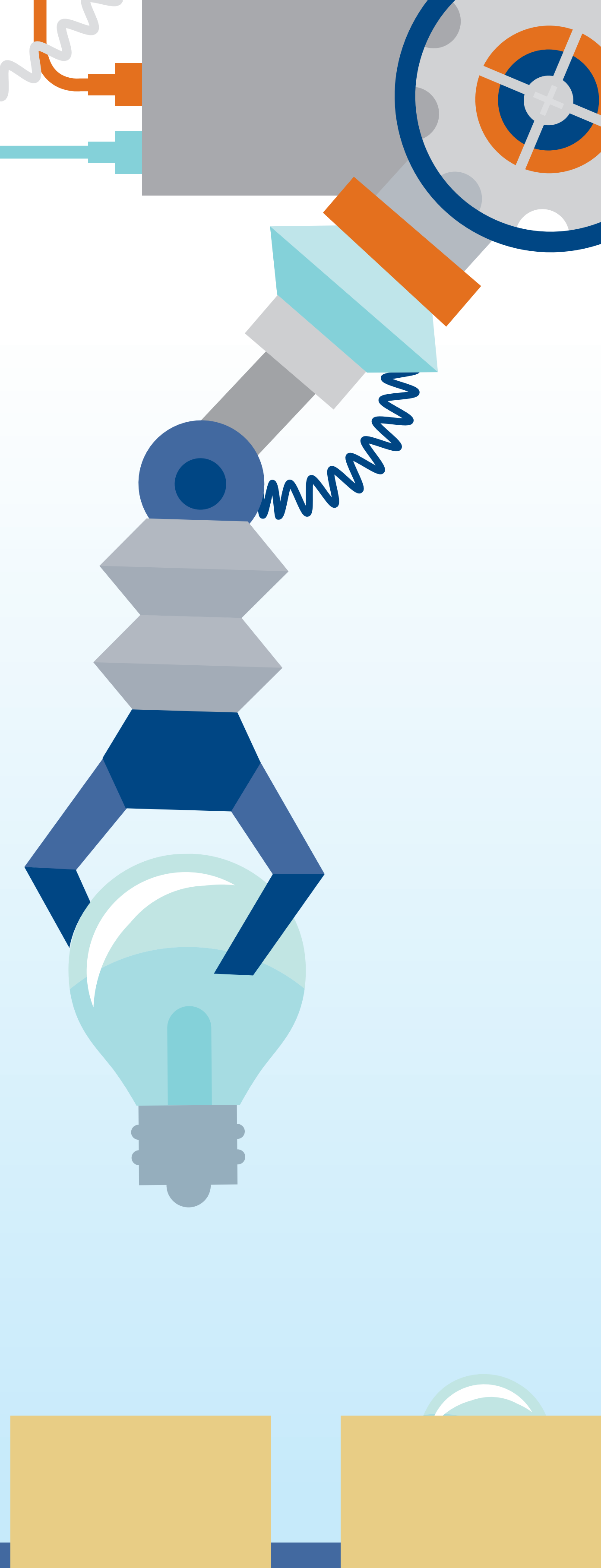
Source: Bureau of Labor Statistics, Citi Research



WHILE INCOME SHARE OF THE TOP 0.1% HAS INCREASED

Source: World of Top Incomes Database, Citi Research





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The Oxford Martin Programme on Technology and Employment is a new research programme established in January 2015 with support from Citi. It has been created to investigate the implications of a rapidly changing technological landscape for economies and societies. The programme will provide an in-depth understanding of how technology is transforming the economy, to help leaders create a successful transition into new ways of working in the 21st century. The programme is part of a wider research partnership between the Oxford Martin School and Citi, analysing some of the most pressing global challenges of the 21st Century.

1. The Changing Nature of Innovation

In addition to providing remarkable achievements in technology…

The 21st century has already brought remarkable technological achievements. The leading corporations of the digital age — including YouTube, Facebook and eBay — barely existed only a decade ago. The Human Genome Project was completed in 2003, the year Skype was first released. The first iPhone was launched in 2007 and in 2010 Google announced their first fully autonomous car. [1]

Yet, the benefits of these developments have not been widely shared. Real median wages have stagnated in about half of all OECD countries since 2000, and have fallen even further behind growth in productivity. Between 1980 and 2000, each pound of UK gross domestic product (GDP) growth, for example, was accompanied by around 90 pence of median wage growth. Over the period 2000 to 2007, the equivalent number was 43 pence.[2]

…the digital age has also decreased labour's share of GDP

As a result, many countries have witnessed significant declines in labour's share of GDP. According to a 2013 study by Loukas Karabarbounis and Brent Neiman, 42 out of 59 countries experienced a fall in the share of GDP accruing to labour — a trend that is also found in emerging economies like China. Crucially, about half of this decline can be explained by the decrease in the relative price of investment goods, which in turn is driven by advances in computer-driven technologies, leading companies to substitute labour for capital in production. In the United States the decline in the labour share has been even more substantial when a small group of highly skilled workers with soaring income is excluded.[3]

Instead of labour, the greatest beneficiaries of the digital age have been shareholders. According to a recent estimate, the three leading companies of Silicon Valley employed some 137,000 workers in 2014 with a combined market capitalisation of $1.09 trillion.[4] By contrast, in 1990 the three largest companies in Detroit had a market capitalisation of $36 billion while collectively employing about 1.2 million workers.

The digital age has benefited consumers but not necessarily workers

To be sure, the digital age has brought indisputable gains to consumers, including the World Wide Web and smartphones, but its impact on the world of work has arguably been more disruptive than anything seen in the past. Thus, less than 20% of American workers now believe that the generation currently entering the workforce will have better lives than themselves. A recent report even predicts that living standards for many low-to-middle income households in the United Kingdom are likely to be lower by 2020 than they were in 2008.[5]

Substantial wealth is being created with only a few workers, and with the exception of a small fraction of highly skilled workers, wages may not rise over their lifetime. Building on a widely discussed paper entitled *The Future of Employment: How Susceptible are Jobs to Computerisation?,* by Carl Benedikt Frey and Michael Osborne, this report examines how the changing nature of innovation, stemming from the digital revolution, is transforming the world of work and the challenges it brings.

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[1] The authors are very grateful to Andrew Pitt and Professor Ian Goldin for guidance in framing this report, as well as to Kathleen Boyle at Citi and Anushya Devendra the Oxford Martin School for their advice and editorial support.

[2] Pessoa and Van Reenen (2013).

[3] Elsby, Hobijn and Sahin (2013).

[4] Chui and Manyika (2014).

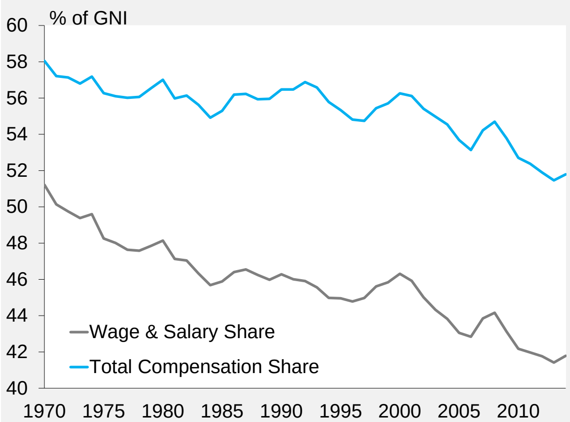
[5] Resolution Foundation (2013).

Labour Share of Income – Citi Economics

Figure 1 shows two measures of the US labour share using data from the European Commission's AMECO database. One measures the wages and salaries of all workers as a share of gross national income (GNI); the other considers total compensation, which includes not only wages and salaries but also payments made by firms for social insurance benefits, as a share of GNI. Both of these measures show a clear downward trend since the 1980s, although the wage and salary share falls more sharply than the total compensation share due to the increased reliance of US workers on retirement and healthcare benefits as a portion of their income.[6]

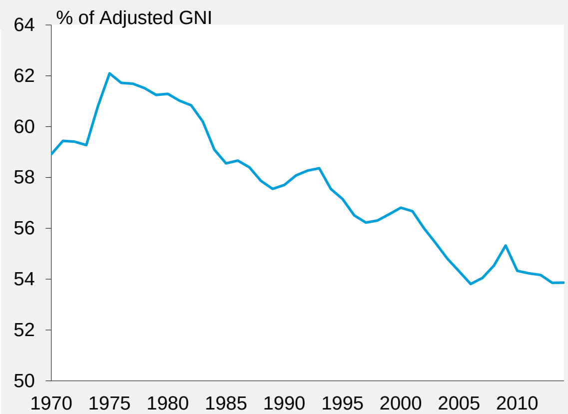
Figure 2 shows a GDP-weighted average of the labour share for 19 advanced economies, also using AMECO data.[7] According to this measure, labour shares on average across the advanced world have declined from around 61% in the mid-1970s to 54% in 2014.

Figure 1. Labour share estimates for the United States



Source: BLS, Citi Research

Figure 2. 19-Economy average labour share estimate



Source: European Commission, Citi Research

[6] It should also be noted that the labour shares shown in Figure 1 are biased downward due the earnings of the self-employed (roughly 10 million workers in the US), who have been increasingly earning more on average than the non-self-employed. Properly adjusting the labour share for the earnings of the self-employed shows that the bias is roughly 1/3 – that is, 1/3 of the drop in the headline labour share is due to the earnings of the self-employed not being properly accounted for. See Michael, Hobijn & Aysegül (2013).

[7] The 19 advanced economies included are: the US, the UK, Austria, Belgium, Denmark, France, Italy, Netherlands, Norway, Sweden, Canada, Japan, Finland, Greece, Ireland, Portugal, Spain, Australia and Germany. The labour share shown is the compensation share – i.e., wages and salaries plus social insurance contributions as a percent of GNI. In addition, in Figure 2 adjustments are made to account for the earnings of the self-employed. Specifically, the earnings of the self-employed are removed from both the numerator and denominator. Thus a more accurate name for the series shown would be the payroll share, defined as the total earnings of all non-self-employed workers as a share of GNI adjusted to exclude the earnings of the self-employed.

The Future of Innovation: Slowdown or Showdown?

In *Capital in the Twenty-first Century*, Thomas Piketty argues that labour's share of GDP tends to fall when the rate of return on capital is greater than the rate of economic growth.[8] As a result, a wealth gap will emerge between owners of capital and those who rely on their labour. For wealth not to concentrate in the hands of the few, it is essential that economic growth be accompanied by the creative destruction of old wealth.

Piketty estimates that growth has failed to outpace the rate of return on capital

Thus, a faster rate of economic growth will reduce the importance of wealth in a country, while sluggish growth will increase it. A key ingredient in inclusive capitalism is therefore continuous creative destruction, giving rise to a new generation of innovators and entrepreneurs. While the digital age has undoubtedly witnessed the rise of a new generation of digital enterprise, growth has failed to outpace the rate of return on capital, according to Piketty's estimations. He shows that the temporary inclusive capitalism of the post-war era, when the rate of economic growth exceeded the return on capital, is over. Instead, slow growth rates are pushing the concentration of wealth back toward Victorian levels — a tendency Piketty proclaims to be the normal state of capitalism.

Innovation is important for growth, and some believe the recent slowdown in economic growth is due to a slowdown in innovation

To be sure, economic growth matters, and innovation matters to economic growth. That the rate of economic growth has recently fallen is therefore particularly concerning. Between 1939 and 2000, average per capita output in the United States grew at 2.7% annually; since 2000, this figure has averaged only 0.9%. While there is ongoing disagreement about the cause of the recent decline in growth rates, economists such as Robert Gordon[9] and Tyler Cowen[10], as well as tech-entrepreneurs like Peter Thiel,[11] have argued that this is the result of a slowdown in innovation. In their view, the extensive type of growth that relies on adding more capital or workers in production — a process that is subject to diminishing returns — has come to an end. For example, over the past 50 years, some 75% of income growth in the United States has been due to rising educational attainment and research intensity.[12] As a much larger share of the population go to college and work in idea-generating industries than was the case 50 years ago, and this transformation can only happen once, there is concern that we may not be able to repeat those gains. Furthermore, many of the benefits from the declining cost of distance, caused by breakthrough inventions such as the railroad, the automobile, the airplane and the telephone, cannot be repeated. The same is true of the invention of electricity and a wide range of household appliances that are now fundamental to our lives.

The extensive type of "catch-up" growth, stemming from adapting and improving existing technologies on a wider scale, is thus unlikely to provide satisfactory growth rates in the rich world. While emerging economies like India and China may help boost the world economy by adapting innovations from previous technological revolutions, the rich world will need to rely more on intensive growth — that is, its capacity to innovate new technologies. The concern is thus that the current digital revolution has not been as transformative as the invention of earlier general purpose technologies (GPTs) like electricity and the steam engine. This concern was raised as early as 1987, when Robert Solow remarked that "you can see the computer age everywhere but in the productivity statistics". After the surge in

[8] Piketty (2014).
[9] Gordon (2012).
[10] Cowen (2011).
[11] Thiel (2014).
[12] Fernald and Jones (2014).

productivity growth of the late-1990s came to a halt, the view that most of the benefits from the digital revolution have already been seen has received more attention.

The changing nature of innovation can explain why wages have failed to grow in tandem with productivity

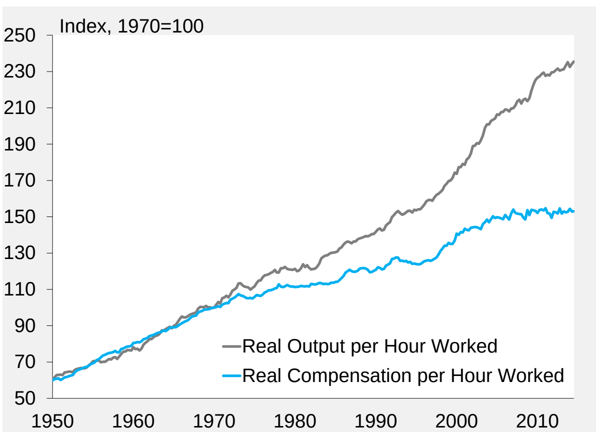
While a decline in the technological dynamism of the rich world would explain the recent fall in productivity and the growing concentration of wealth highlighted by Piketty, it does not explain why wages have failed to grow in tandem with productivity. One explanation is the changing nature of innovation. Although technology can raise productivity and boost wages, it can also take the form of capital that substitutes for labour. In that case, productivity growth will simply enhance capital's share of income, and thus the concentration of wealth.

The Growing Gap between Productivity and Pay – Citi Economics

Figure 3 shows the gap between compensation of workers and their productivity for the United States, considering data from the Bureau of Labor Statistics. The figure compares the total output per hour worked in the economy (a measure of productivity) against the hourly compensation rate for all workers, both adjusted for inflation. There has been a growing gap between the two for decades. Since 1980, productivity has grown at an annual average rate of roughly 2%, compared to just under 1% annual average growth for real hourly compensation.

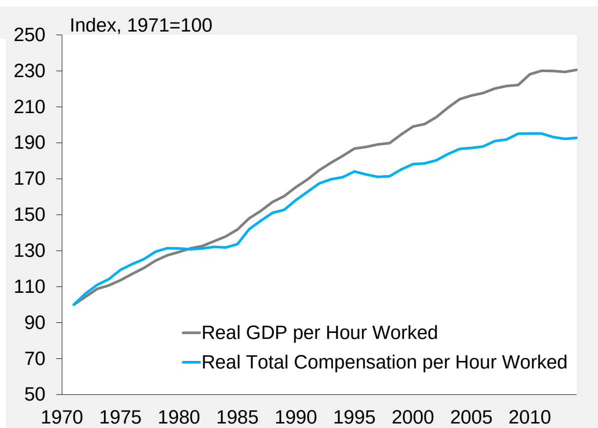
Figure 4 shows a GDP-weighted average estimate of the so-called productivity gap for 16 advanced economies.[13] Consistent with the US story, the advanced world as a whole has also seen productivity decouple from the compensation paid to workers. However, the decoupling for the advanced-economy as a whole is not as severe as it is for the US alone. Since 1980, advanced-economy productivity has grown at an annual average rate of 1.7%, compared to 1.1% annual average growth for advanced-economy real hourly compensation. This 0.6 percentage point average growth rate difference between productivity and compensation in the advanced world is still nonetheless meaningful. It implies that, over time, a greater fraction of output produced per hour worked in the advanced world has gone to property owners in the form of profits rather than to workers in the form of compensation – a trend consistent with declining labour shares.

Figure 3. Gap between productivity and pay in the United States



Source: : BLS, Citi Research

Figure 4. Advanced economy average productivity gap



Source: European Commission, Citi Research

[13] Figure 4 includes data for 16 advanced economies. Relative to those included in Figure 2 Australia, Austria and Greece were dropped due to data limitations. Output is deflated with the GDP deflator, whereas compensation is deflated by national consumer price indexes.

Brynjolfsson and McAfee argue that we are not likely to see a growth problem resulting from a slowdown in innovation as workplaces restructure and productivity growth follows

The view that a widening gap between productivity and pay is due to increased usage of labour-substituting capital is favoured by Erik Brynjolfsson and Andrew McAfee, arguing that the reason why wages have failed to keep pace with productivity is that ordinary workers are unable to adapt to an ever increasing pace of technological change.[14] As a result, many workers are seeing their skills made redundant by new computer technologies. According to Brynjolfsson and McAfee, we are not likely to have a growth problem resulting from a slowdown in innovation: technological advances increase productivity only after long lags. As workplaces gradually restructure to accommodate new technologies, they argue, productivity growth will follow. Still, the concentration of wealth that Piketty forecasts may be exacerbated as computer-controlled devices are increasingly substituted for human workers. According to a recent study by Carl Benedikt Frey and Michael Osborne, as many as 47% of US jobs are at risk for automation over the forthcoming decades.[15]

While Joseph Schumpeter famously noted that long-run growth occurs via structural change, which may inflict pain, this report will argue that the recent trend of declining living standards is not just the result of structural change. It is caused by the changing nature of innovation.

The Digital Age: Why This Time is Different

Innovation this time around benefits the few rather than the many which is cause for concern

There is reason to be concerned that we are experiencing an era in which innovation benefits the few rather than the many. Because most individuals are consumers and producers, new technologies will have an impact on people's living standards in both capacities, positively or negatively. In the past, some innovations have benefited ordinary people both as producers and consumers.[16] Others have negatively impacted workers in production while helping consumers.

To be sure, an important feature of the Industrial Revolution was that it benefited people both as producers and consumers over the long-run. In particular, the adoption of the assembly line created vast employment opportunities for low-skilled workers and enabled corporations such as the Ford Motor Company to manufacture the Model-T at a sufficiently low price for it to become the people's vehicle. By contrast, the digital revolution has mainly benefited ordinary people as consumers. While the World Wide Web provides many things for free, new employment opportunities have mainly been created for highly skilled workers.[17] At the same time, the potential scope of automation has rapidly expanded, substituting for ordinary workers in a variety of domains.[18] In short, while the digital age has been a blessing to consumers, it is changing the world of work in ways that may make a growing share of workers worse off (in their capacity as producers) over the long-run.

[14] Brynjolfsson and McAfee (2014).
[15] Frey and Osborne (2014).
[16] Glaeser (2014).
[17] Berger and Frey (2014).
[18] Frey and Osborne (2013).

The digital age has broken the historical observation that shares in national income accrue to capital and labour in a constant manner

So far, the digital age has been the age of capital rather than the era of labour. This sheds a different light on the six stylised facts about economic growth Nicholas Kaldor famously published in 1957. Having observed remarkable historical consistency in the shares of national income accruing to capital and labour respectively over longer periods of time, he concluded that these shares are roughly constant — an assumption that is still at the heart of many growth models. [19] As the labour share of GDP has steadily declined over the past decades, across countries, this assumption has nevertheless become difficult to maintain.

Digital technologies can also make capital less relevant

Yet, in the future, digital technologies could also increasingly substitute for capital. Crucially, the digital economy allows many goods and services to be codified, and once codified, they can be digitised and replicated. Furthermore, as has been pointed out by Erik Brynjolfsson, Andrew McAfee and Michael Spence: "digital copies can be made at virtually zero cost and transmitted anywhere in the world almost instantaneously, each an exact replica of the original."[20] Consider Twitch, a live streaming video platform employing some 170 workers, which was acquired by Amazon.com for $970 million in September 2014. While receiving venture capital (VC) funding, the company did not need much physical capital relative to the industrial giants of the past. The same is true of Instagram and WhatsApp: both did not need much capital investment to get started, and thus not many workers to build up the new capital.

While digital technologies increasingly substitute for labour, they may also reduce the demand for capital. In the digital age, innovators and entrepreneurs, not workers or investors, will be the main beneficiaries.

Meeting the Challenge

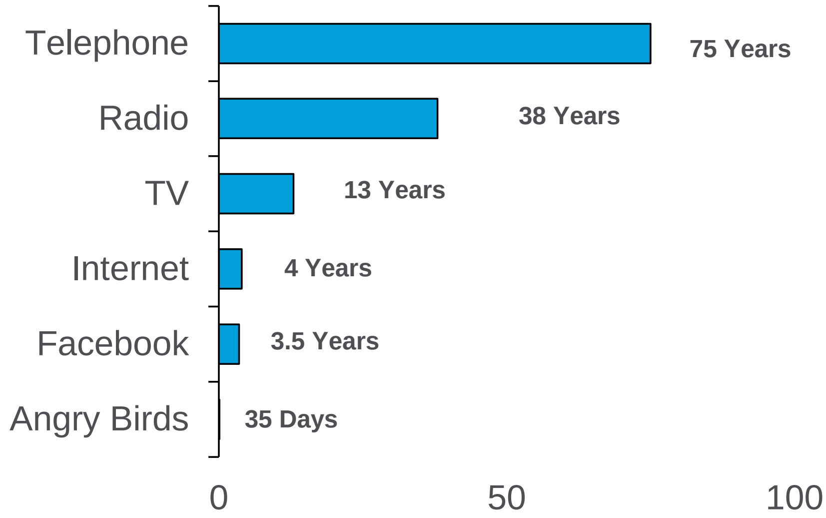
The speed of technology diffusion has increased…

Technologies are diffusing much faster now than they have in the past. Historically, countries have adopted a new technology on average 45 years after its invention, although the lag has shortened over time. It took on average 119 years for the spindle to diffuse outside Europe. By contrast, the Internet has spread across the globe in only seven years. The extent to which new technologies have been adopted still varies substantially across countries and can account for some 25% of the differences in nations' per capita income today.[21] However, as adoption lags become shorter, the rich world's advantage of being an early adopter will inevitably decrease.

Figure 5 shows the shortening of the lag in adoption, from telephones needing 75 years to get to fifty million users, to Angry Birds taking just 35 days. Services like Instagram reached 300 million users in just four years and Forbes recently noted that WhatsApp gained more followers in its six years of existence (700m) than Christianity did in its first nineteen centuries.

[19] Kaldor (1957).
[20] Brynjolfsson, McAffe and Spence (2014).
[21] Comin and Hobjin (2010).

Figure 5. Time to reach 50 million users



Source: Citi Digital Strategy Team

…and looks to continue to do so

There are good reasons to believe that the pace of technological innovation has, if anything, increased over time, and will continue to do so. Digital technologies are connecting almost everyone, allowing people to share ideas. Scientific knowledge is becoming readily available to anybody eager to learn — to be sure, there is no mechanism that automatically turns science into technology, but its availability allows people to combine previous discoveries in innovative ways. Finally, the companies leading the digital transformation are already vastly profitable, compared to companies leading past technological revolutions. For example, the operating income per employee at Google is roughly six times that of IBM, and about 12 times that of General Motors.

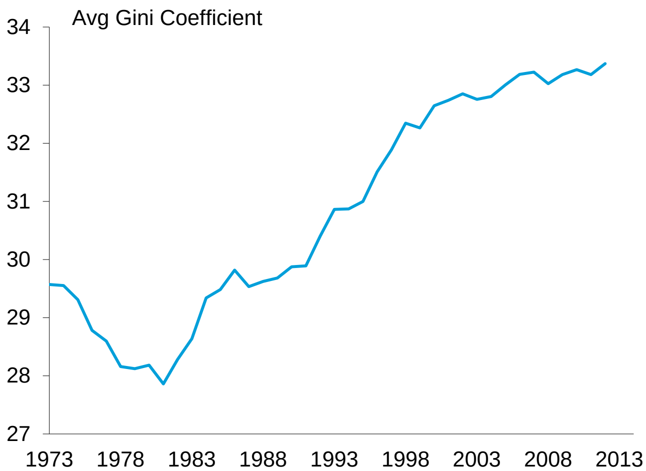
Digital technologies have created enormous wealth and a sharing economy

Digital technologies will continue to create enormous wealth. Meanwhile, a sharing economy is emerging in which more things are becoming available for free, leading to unprecedented benefits for consumers. Airbnb connects hosts and travellers, providing consumers with much cheaper accommodation. In a similar way, Uber uses a smartphone application that connects passengers with drivers, substantially reducing costs for consumers. Technology also offers new possibilities for entrepreneurs. Etsy, an online marketplace for arts and crafts, enables artisans to reach global markets even from deprived areas.

But, as digital technology increasingly takes the form of capital that substitute for labour, inequality is likely to continue to surge

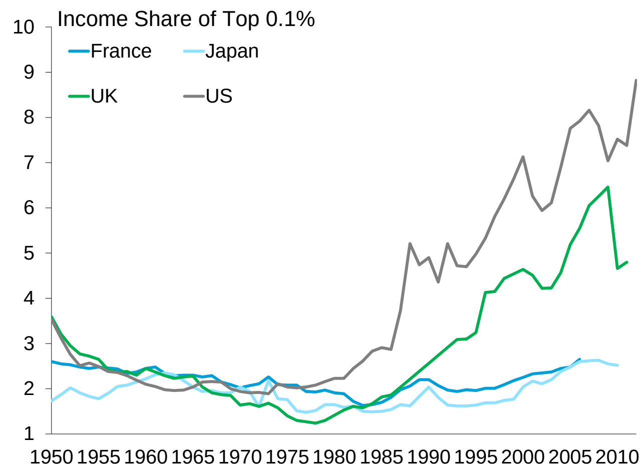
Nevertheless, the digital age has also left many people behind. Income inequality is soaring, as evidenced by rising Gini coefficients in advanced economies (Figure 6),[22] especially at the top of the income distribution, most prominently in the US and the UK (Figure 7). As technology increasingly takes the form of capital that substitute for labour, inequality is likely to continue to surge. Breaking this trend will require a shift in mindsets, policies and investments. This report will seek to understand where technological change is leading us and the challenges that lie ahead.

Figure 6. Average advanced economy Gini coefficient



Source: Solt (2014), Citi Research

Figure 7. Top 0.1% income shares, excluding capital gains



Source: World of Top Incomes Database, Citi Research

[22] The Gini coefficient shown in Figure 6 is net of redistribution. That is, it is a measure of how unequal the distribution of earnings is after taxes and transfer payments by the government have been accounted for. Market measures of the Gini coefficient — i.e. before redistribution — generally show higher levels of inequality, as most advanced economies have progressive social welfare systems. The data show a GDP-weighted average of Gini coefficients considering 19 economies (the same as those included in Figure 2 and some from Frederick Solt's inequality database, which aggregates data from various sources including the Luxembourg Income Study, See Solt (2014).

2. Technology at Work

The concern over technology rendering the skills of the workforce redundant is hardly a recent one. To be sure, the type of creative destruction Joseph Schumpeter famously argued was at the heart of long-run growth and prosperity has increased the living standards of many over more than two centuries. Nevertheless, technological progress has also created undesired disruptions. Historically, it was not so much the lack of innovation and entrepreneurial spirit that had hindered progress, but rather powerful interests promoting the technological status quo. The great Roman writer, Pliny the Elder, nicely illustrates this with a story from the reign of the Emperor Tiberius, where an inventor had discovered a way of manufacturing unbreakable glass. In anticipation of a reward he approached the emperor to display his invention. Fearing the creative destruction that would follow the diffusion of this technology, however, the Emperor had the man sentenced to death.[23]

This story is not an isolated example. Indeed, it is illustrative of a broader tendency of how the ruling elite often blocked technological progress in the past. Under Emperor Vespasian, who ruled Rome between AD 69 and 79, the inventor of a machine for transporting columns to the Capitol was denied the use of his invention, with the Emperor declaring: "How will it be possible to feed the populace?"[24] Even as late as 1589, when William Lee invented the stocking frame knitting machine, Queen Elizabeth I argued that: "Thou aimest high, Master Lee. Consider thou what the invention could do to my poor subjects. It would assuredly bring to them ruin by depriving them of employment, thus making them beggars."[25]

The combination of central government controlling progress and the lack of incentives to promote creative destruction thus held innovation and entrepreneurship back for a long time. In fact, to understand events like the Industrial Revolution, we need to understand the political economy of technological progress.

The Political Economy of Technological Change

How the benefits of innovation are distributed is key to whether the innovation will be socially accepted

The economic historian Joel Mokyr has persuasively argued that unless all people in a society accept the verdict of the market, innovations are likely to be resisted through political activism. In other words, the balance between job conservation and creative destruction reflects the balance of power in society, and how the benefits from innovation are being distributed.

The British Industrial Revolution provides a case in point for how new institutional frameworks can lay the foundations for long-run growth and prosperity. As Parliamentary supremacy was established over the Crown, following the Glorious Revolution of 1688, the craft guilds in Britain lost most of their political power.[26] With merchants and inventors gaining political influence, legislation was passed in 1769 making the destruction of machinery punishable by death.[27] The shifting sentiment of the government towards the destruction of machinery was explained by a resolution passed after the Lancashire riots of 1779, stating that: "The sole cause of great riots was the new machines employed in cotton manufacture; the country

[23] Acemoglu and Robinson (2012)
[24] ibid
[25] ibid
[26] Nef (1957).
[27] Mokyr (1990).

notwithstanding has greatly benefited from their erection [and] destroying them in this country would only be the means of transferring them to another [...] to the detriment of the trade of Britain."[28] To be sure, there was still resistance to technology displacing artisan workers. The "Luddite" riots between 1811 and 1816 partly reflected the fear of mechanisation. Nevertheless, the Crown and the guilds lacked the political influence to halt creative destruction.

As the Industrial Revolution spread across the Atlantic and to mainland Europe, there were still forces that counteracted innovation. On the continent, where the guilds were still largely present, innovators often left for less regulated markets. For example, Heinrich Engelhard Steinweg, the founder of Steinway & Sons, famously left Germany for New York with his five sons in 1850, as the local guilds' heavy regulation of the piano-making process did not allow for the Steinway production methods. Over 150 years later, New York is still the leading factory for Steinway pianos, alongside Hamburg.

The general tendency has been towards embracing technological progress as workers gradually see the benefits of technological change

While the regulation of innovation activities may have long-lasting effects, the general tendency since the Industrial Revolution has been towards embracing technological progress. It would be a mistake, however, to conclude that this shift in attitudes was only a result of a shift in political power. Although working conditions were often horrific, the sustained progress that followed was as much a result of many ordinary workers gradually seeing the benefits of technological change.

Steam Powered Production: From the Artisan Shop to the Factory System

Low-skilled workers benefited from the Industrial Revolution as it simplified the tasks workers had to perform in production

An important feature of the manufacturing technologies associated with the Industrial Revolution is that they mainly benefited low-skilled workers by simplifying the tasks workers had to perform in production.[29] This skill replacing process occurred as the artisan shop was gradually displaced by the factory system, and picked up pace as production was increasingly mechanised, following the adoption of steam power.[30] As a result, manual work that had previously been performed by highly skilled artisans was now decomposed into specialised sequences.

Key innovations in manufacturing, such as continuous-flow production and interchangeable parts, were even specifically designed for low-skilled workers. At Ford, the new assembly line introduced in 1913 turned a one-man job into a 29-man operation, reducing the overall work time by 34%. This allowed complex products to be assembled from mass-produced individual components; work that required less skill, but more workers, to perform.[31]

The differences in productivity between the factory and the artisan shop is nicely illustrated in the production of plows. In one artisan shop, two men spent 118 man-hours using hammers, anvils, chisels, hatchets, axes, mallets, shaves and augers in 11 tasks to produce a plow. By contrast, a steam-powered plow factory employed 52 workers performing 97 distinct tasks to produce a plow in just about 3.75 man-hours.

[28] Mantoux (2006).
[29] Braverman (1977); Goldin and Katz (1998).
[30] Atack, et al. (2008a).
[31] Bright (1958).

Increasing demand for low-skilled workers plus a surge in productivity helped boost employment and wage growth over the course of the 19th century

The combination of increasing demand for low-skilled workers, and the surge in productivity following the transition to the factory system, helped boost employment and wage growth over the course of the 19th century, benefiting ordinary people as producers. According to some estimates, real wages nearly doubled between 1820 and 1850.[32]

A crucial feature of technological change in the 19th century was that it benefited ordinary people both as producers and consumers. While the factory system provided vast employment opportunities for unskilled workers, it also enabled Ford to manufacture the Model-T at a sufficiently low price for it to reach the mass market. It was these two processes of growing wages and falling prices of consumer goods that created the modern middle class. Some economic historians such as Gregory Clark have even argued that ordinary workers were the greatest beneficiaries of the Industrial Revolution.

Electrification and the Demand for Skills

The shift in demand for higher-skilled workers can be traced to the switch to electricity

The idea that skilled workers have been the main beneficiaries of technological progress is largely a 20th century phenomenon. This shift in demand for skills can be traced to the switch to electricity and the removal of the steam engine, leading to a complete reorganisation of production.[33] Crucially, the restructuring of the factory that followed significantly reduced the demand for maintenance workers as well as unskilled labourers who had previously carried unfinished goods and tools.

Furthermore, the shift to continuous-process and batch production methods reduced the demand for unskilled workers in many assembly tasks. In short, while factory assembly lines had required vast amounts of human work, electrification allowed many stages in production to be automated. This, in turn, increased the demand for relatively skilled workers to operate the machinery.

The shift to mass production was also helped by the transportation revolution and led to the advent of multinational corporations

The transport revolution played an important role in incentivizing the shift to mass production, as it lowered the cost of shipping goods both domestically and internationally.[34] Markets for artisan goods, that had previously been local, now became subject to increased competition, forcing companies to raise productivity through mechanisation in order to maintain their competitive edge. With the emergence of the multinational corporation, management tasks became more complex, increasing the demand for managerial and clerking workers.

Crucially, this transformation did not lead to the type of technological unemployment John Maynard Keynes predicted in the 1930s. Workers adapted by making their skills complementary to the arrival of new technologies. In the United States, for example, the high school movement was essential to the transformation of the corporation, as the office entered a wave of mechanisation, with typewriters, dictaphones, calculators, and address machines. An important feature of these technologies is that while they reduced the cost of information processing, they increased the demand for high school-educated workers. Indeed, since electrification, the story of the 20th century has been what Claudia Goldin and Lawrence Katz have referred to as "the race between technology and education."

[32] Lindert and Williamson (1983)
[33] Gray (2013)
[34] Atack et al. (2008b)

The Computer Revolution and the Squeezed Middle

While early 20th century office machines increased demand for clerking workers, recent developments in computer technology have permitted such tasks to be automated.

This trend began with the first commercial uses of computers around 1960 and continued through the development of the World Wide Web in the 1990s. Between 1945 and 1980, as the cost of computing declined at an annual rate of 37%, most telephone operators were displaced.[35] In addition, the first industrial robot was introduced in the 1960s, and a decade later airline reservations systems led a wave of improvements in self-service technology.

Throughout the 1980s and 1990s, the costs of computing fell even more rapidly, on average by 64% per year.[36] During this period bar-code scanners and cash machines penetrated retail and financial industries. Furthermore, the advent of the personal computer (PC) in the early 1980s, and its functions, contributed to the displacement of many copy typist jobs and allowed repetitive calculations to be automated.

Employment in middle-skilled manufacturing and clerical occupations experienced a secular decline in the 1970s due to the impact of computers

The impact of computers on labour markets is captured in an influential paper by David Autor, Frank Levy, and Richard Murnane, showing that middle-skilled manufacturing and clerical occupations have experienced a secular decline in employment since the 1970s.[37] The common denominator for these jobs, the authors document, is that they are intensive in rule-based activities (or routine tasks) which can be easily specified in computer code.

Hence, the rapid improvements in computer technology over the last few decades have provided employers with ever cheaper machines that can replace humans in many middle-skilled activities such as bookkeeping, clerical work and repetitive production tasks. The result has been a shift in the occupational structure of the labour market in most developed countries over recent decades, with a hollowing-out of traditional middle income jobs.

Computers and industrial robots together have substituted for the same type of routine work, reallocating workers to manual service occupations

Importantly, as computers and industrial robots have substituted for the same type of routine work that was once done by thousands of workers on assembly lines, most of these workers have reallocated to manual service occupations.[38] This is because, at least in the past, computers and robots have been less capable of driving trucks, waitressing and cleaning than most humans.

At the same time, with falling prices of computing, problem-solving skills have become relatively productive, explaining the substantial employment growth in occupations involving cognitive work where skilled labour holds a comparative advantage. For example, text and data mining has improved the quality of legal research as constant access to market information has improved the efficiency of managerial decision-making — that is, tasks performed by skilled workers at the higher end of the income distribution.

[35] Nordhaus (2007)
[36] ibid
[37] Autor, Levy and Murnane (2003).
[38] Autor and Dorn (2013).

The current trend towards job polarisation is best captured by Maarten Goos and Alan Manning's work on "Lousy and Lovely Jobs", with employment growth in high-income cognitive jobs and low-income manual occupations, accompanied by the disappearance of middle-income routine jobs.[39]

Evidence of Polarisation in Jobs and Wages

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There is a compelling case that robotics and other technological marvels will have a dramatically positive overall effect on living standards. Automation will hasten the growth of labour productivity, and aggregate welfare will rise in tandem with real wages. *But*, not all technological changes are created equal. The extent to which an individual gains or losses from automation will depend on their level of skill as well as the degree of 'skill bias' embedded in new technology. In other words, it will depend largely on whether that individual is a substitute or a complement to the robot knocking on their workplace door.

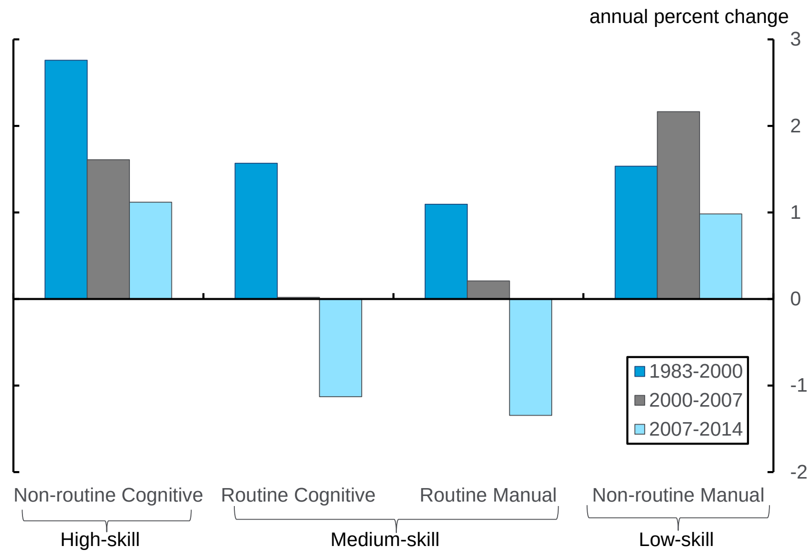
The dominant narrative characterising how global labour markets are responding to technological change is one of 'job polarisation': the fact that employment growth has been most robust at the highest and lowest ends of the skills spectrum. The middle skill jobs, in contrast, contain the highest concentration of routine tasks and are thus relatively easy to automate.[40]

Much of the job growth in the US in recent decades has occurred in high- and low-skilled occupations, leading to a polarised labour market

Evidence for job polarisation in the US is shown in Figure 8, which tracks employment trends since the 1980s for professions falling into three different categories of skills. High- and low-skilled jobs involve tasks that are non-routine, requiring either cognitive capacity or manual labour to complete them. At the high end, these include jobs in managerial and professional occupations, such as those in law, architecture and design, and finance; at the low end, jobs requiring manual labour are found in the construction sector, in installation and maintenance, and in the transportation and shipping sectors (e.g. truck drivers), to name a few. In the middle are routine jobs that require the use of either cognition or manual labour to complete tasks. Routine cognitive tasks are performed in sales and office-related professions (e.g. administrative secretaries); routine manual tasks are done mainly in the services sector, in healthcare support or food preparation roles, for example. Figure 8 uses data from the US Bureau of Labor Statistics' (BLS's) Household Survey to make the point that much of the job growth witnessed in the US in recent decades has occurred in high- and low-skilled occupations – for those possessing cognitive or manual skills that are not easily automatable.

[39] Goos and Manning (2007).
[40] A detailed analysis of the link between automation and job polarisation is provided in Autor, D. (2014a)

Figure 8. Employment growth in the United States reflecting job polarisation

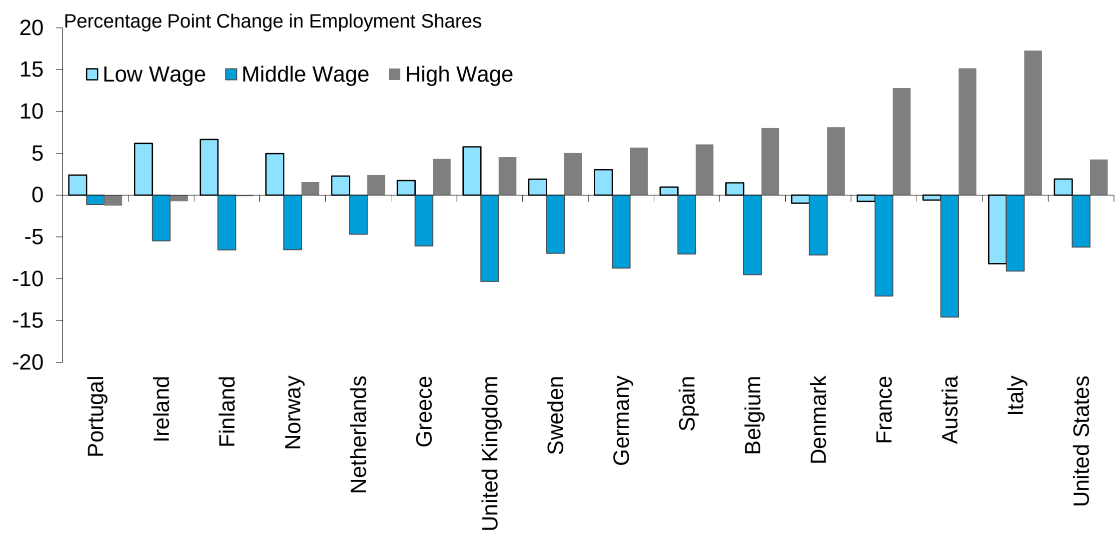


Source: Valletta (2015) Note: Employment categories are based on the author's calculations of BLS data from the Household Survey

Job polarisation is an issue not just in the US, but across Europe as well

Figure 9 suggests that the US experience of job polarisation is not unique. Across a broad swath of advanced economies, occupations at the middle of the skills spectrum – under the assumption that these occupations pay average wages – have fallen as a share of total employment, whereas occupations at low or high skill classifications have gained. The data are not as granularly defined as those in Figure 8, which again separates routine job tasks from non-routine ones, but they do lend support to the hypothesis that the phenomenon of automation carving out jobs at the middle of the skill distribution is occurring globally.

Figure 9. Change in employment shares by occupation, 1993-2006



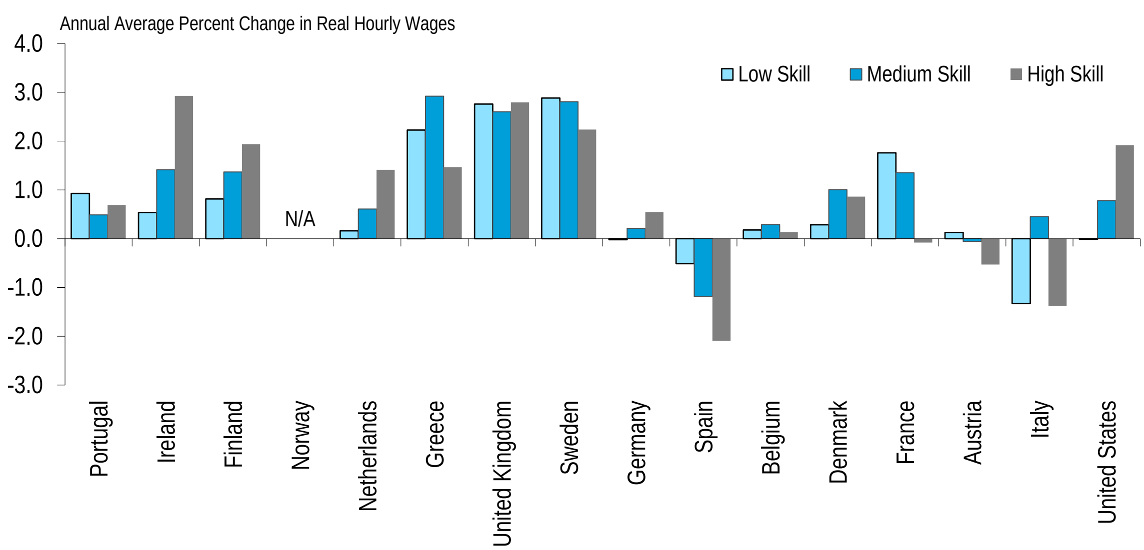
Source: Autor (2010). Note: Wage categories are based on average wage levels at the start of the period measured

What is the implication of job polarisation for wages? It is not immediately clear that wages should accelerate at both ends of the skill distribution. The reason is that while it may be possible for workers to quickly 'skill down' – namely, to give up an automated middle-skill job to take a lower-skilled job which is more heavily in demand in the labour market – it may not be as easy for them to 'skill up' to take higher-skilled jobs for which wages are accelerating. To skill up requires increased cognitive capacity, which tends to come about from education and job training – both slow moving processes. Indeed, this is why some have dubbed our era as a 'race between technology and education.' The former occurs rapidly and disruptively; the latter very slowly. The end result is that additional labour supply keeps wage growth relatively muted at the bottom, while its absence causes wages to accelerate quickly at the top.

It is easier for workers to 'skill down' the job curve but more difficult for them to 'skill up' leading to an increase in wages on the top of the skill distribution

This appears to empirically be the case when we examine the data on wage growth globally. In Figure 10, we aggregate the data on hourly wages from the World Input-Output Database to measure inflation-adjusted real wage growth for three occupational categories (low-, medium- and high-skill) on the basis of educational attainment.[41] The trends in Figure 10 do not point toward polarisation in wages. What does appear to be the case, in general, is that wages for higher-skilled occupations have grown faster than those for middle- or lower-skilled occupations. This trend is true for eight of the 15 countries shown in Figure 10, many of which are large (apart from Spain, Italy and France, where wages in higher-skilled professions have not fared well, perhaps due to policies limiting labour-market flexibility in those countries). The eight countries in which wages at the top of the skill distribution have grown faster than wages at the middle or bottom account for more than 75% of the GDP produced by all 15 countries in the sample. Growing wage inequality in these countries has important policy implications, as well as implications for financial markets, which we elaborate on in a later section of this report.

Figure 10. Change in employment shares by occupation, 1993-2006



Source: Timmer (2012) Note: The hourly wage rate is calculated as total labor compensation divided by total hours worked. We deflate the reported nominal data using national consumer indexes.

[41] The WIOD data counts jobs requiring lower secondary or primary education as "low skill," those requiring post or upper secondary education as "medium-skill," and those requiring first or second stage tertiary education as "high-skill."

Lessons from History: What's Next?

How will technological progress alter the occupational structure of labour markets in the twenty-first century? Unfortunately, economic history does not necessarily provide obvious guidance for predicting how technological progress will reshape labour markets in the future.

Technological progress has shifted the composition of employment and the demand for skills

To be sure, over the past century technological progress has vastly shifted the composition of employment, from agriculture and the artisan shop, to manufacturing and clerking, to service and management occupations. Doing so, it has also shifted the demand for skills. But the relationship between new technologies and the demand for skills has been far from monotonic.

The Computer Revolution led to a shrinking of employment in the middle and growth in low-skill and low-income service jobs

During the Computer Revolution of the 1980s, the invention and diffusion of the PC favoured workers with a college education, but from the early 1990s that pattern changed. Although new jobs associated with the computer, such as database administrators and software engineers, still favoured skilled workers, the US economy experienced a slowdown in the demand for skills, while the share of employment in the middle even shrank. In the 2000s the change became more pronounced: employment among the least-skilled workers soared whereas the share of jobs held by middle- and high-skill workers declined. Work involving complex but manual tasks, like cleaning or driving trucks, became more plentiful. Both in the United States and in Europe, since 2000 low-skill and low-income service occupations have experienced job growth. At the same time, high-skilled workers are now taking on jobs traditionally performed by low-skilled workers, pushing low-skilled workers even further down, and sometimes even out of the workforce.[42]

There is concern that jobless economic recoveries have become the new normal

The decline in routine employment has been additionally spurred by the Great Financial Crisis, and there is indeed growing concern about the jobless recovery. Some even predict that jobless recoveries may become the new normal. According to a recent study, a long-term decline in routine occupations is occurring in spurts as these jobs are lost during recessions.[43] This implies that future recoveries will likely be jobless as digital advancements now allow distressed companies to shed middle-income jobs in favour of automation – something that is happening across industries, including manufacturing, wholesale and retail trade, financial services, and even public administration.

While the concern over technological unemployment has so far proven to be exaggerated, the reason why human labour has prevailed relates to its ability to adopt and acquire new skills by means of education. Yet as computerisation enters more cognitive domains this will become increasingly challenging. To predict the future we therefore need to understand what is happening in technology.

In order to understand technology's impact on labour markets, we need to understand the direction of technological progress

A well-known statement commonly attributed to Niels Bohr, is that "God gave the easy problems to the physicists." While most conditions in social sciences are not timeless, physics is a closed system in which invariant statements can be made given sufficient boundary conditions. Arguably, technological progress has followed an evolutionary process whose path can never be predicted in detail, but we do have some idea of the near term boundary conditions in engineering. To understand how technology may impact on labour markets in the future, this report will argue that we need to understand the direction of technological progress, and thus the near term bottlenecks to our engineering capabilities.

[42] Beaudery, Green and Sand (2013).
[43] Jaimovich and Siu (2012).

3. Technology in the 21st Century

Automation prior to the 21st century predominately affected only a circumscribed set of routine manual tasks. Increasingly, however, technology is enabling the automation of tasks once thought quintessentially human: cognitive tasks involving subtle and non-routine judgment. The boundaries surrounding the tasks achievable only with human labour continue to contract at an alarmingly accelerating rate. The rapid pace with which technology enables new forms of automation is illustrated by Autor, Levy and Murnane,[44] who write: "Navigating a car through city traffic or deciphering the scrawled handwriting on a personal check — minor undertakings for most adults — are not routine tasks by our definition.'" Today, both the tasks of navigating a car and deciphering handwriting are automatable.

The Big Data Revolution and the Digitisation of Industries

Although machines cannot think and reason the same as humans do, they are capable of performing more and more human tasks

Machines, as yet, do not think and reason as we do. Human reasoning and our ability to act is built on the deep tacit knowledge we hold about our environment. In the case of deciphering handwriting, we employ intuitive knowledge of how a hand-held pen interacts with paper (usually giving smooth lines) to ignore irrelevant imperfections in the paper. Further, our judgment of the identity of words is informed by our deep knowledge of the typical structure of language. We also make use of contextual clues to arrive at the most likely interpretation of text, considering the intentions of the author and the circumstances under which the text was written. Most of these cognitive processes are far beyond the scope of what algorithms can currently reproduce. However, clearly, this does not mean that they are incapable of performing human tasks: machine learning algorithms (a subfield of artificial intelligence that aims to build algorithms that can learn and act) were responsible for reading greater than 10% of all the cheques in the US in the late 1990s and early 2000s.

Big data has been a driver for automating complex tasks that close the gap with human knowledge

Recent technologies for automating complex tasks have closed the gap with human knowledge by employing the increasing availability[45] of relevant *big data*. For example, modern algorithms for machine translation are built on large corpora of human-translated text. In particular, the success of Google Translate is built on Google amassing more than 10^12 translated words.[46] These include two hundred billion words from official United Nations (UN) documents, which are required to be translated into the six official UN languages. The algorithms are then able to identify short phrases (*n-grams*) that are commonly translated to equivalent phrases in other languages, allowing it to substitute for such phrases to perform remarkably efficient translation. While Google's algorithms are unable to understand the deep semantics of this text, for many applications the big data approach is more than sufficient.

[44] Autor, Levy and Murnane (2003).
[45] Predictions by Cisco Systems suggest that the Internet traffic in 2016 will be around 1 zettabyte (1 × 10^21 bytes) (Cisco, 2012). In comparison, the information contained in all books worldwide is about 480 terabytes (5 × 10^14 bytes), and a text transcript of all the words ever spoken by humans would represent about 5 exabytes (5 × 10^18 bytes) (UC Berkeley School of Information, 2003). It seems clear that data is now available at an unprecedented scale.
[46] Mayer-Schönberger, and Cukier (2013).

Here data serves as a substitute for the implicit knowledge human workers possess. Such data (termed training data in the parlance of machine learning) is usually drawn from recorded human judgment:[47] for example, the data might be human-provided labels of the translation of a piece of text. As such, these data can be seen as a way of encoding human knowledge such that it can be extended to many different iterations of a task. That is, algorithms allow for scaling beyond the human: a single dataset of human judgments might be drawn upon to make decisions many times a second for years. As a result, computerisation is no longer confined to tasks that can be written as rule-based procedures a priori, but is spreading to any task where big data becomes available.

Big data is increasing the types of work that are susceptible to computerisation, including retail and sales occupations

Retail and sales occupations may become susceptible to computerisation due to the rise of big data. As an example of the scale of data now employed in retail, Walmart's databases contain more than 2.5 petabytes (2.5 × 10^15 bytes) of information.[48] The algorithmic recommender systems used by Netflix, Amazon and Spotify are built on big data characterising the preferences and spending patterns of their large customer bases. These recommender systems use sophisticated machine learning techniques to compare a particular customer's purchases to those of other customers, and, with instant recall of large product catalogues, can provide product recommendations that, in many instances, may be more useful than those of a human salesperson. Finnish company walkbase is taking a similar approach to physical retail, using big data analytics on in-store customer behaviour in order to offer in-store product recommendations. We expect these technologies to apply increasing competition to human retail assistants.

The ability to store and process large amounts of data is helpful to the legal industry…

Legal services are also being affected by the ability of computers to store and process big data. In particular, algorithms are increasingly substituting for tasks performed by paralegals, contract and patent lawyers. More specifically, law firms now make use of systems that can scan thousands of legal briefs and precedents to perform document review and to assist in pre-trial research. As an example, Symantec's eDiscovery platform is able to perform all tasks "from legal hold and collections through analysis, review, and production", and proved capable of analysing and sorting more than 570,000 documents in two days.[49] Similarly, there are an increasing number of businesses, including Talent Party, Jobandtalent, Knack and Electronic Insight, using big data to automate recruitment.[50] In particular, these firms use millions of CVs (résumés) and profiles characterising career trajectories in order to understand what makes different candidates suitable for different roles. These data can then be compared against those gathered on a specific candidate from the patterns of language used in their applications, and, in some cases, by having them play browser games. The power of algorithms to work with this big data in a way that is impossible for humans is likely to threaten employment in recruitment.

…and leading to the automation of diagnostic tasks in healthcare

In health care, the increasing availability of big data is leading to the automation of diagnostics tasks. For example, IBM's Watson system is being employed by oncologists at Memorial Sloan-Kettering Cancer Center[51] to suggest treatment options for cancer patients. These suggestions are informed by data from 600,000 medical evidence reports, 1.5 million patient records and clinical trials, and two million pages of text from medical journals. With reference to this data, Watson can

[47]The human experts who provide such training data are rarely compensated in proportion to the value that their data provide.
[48]Cukier. (2010).
[49]Markoff (2011).
[50]Wall (2014).
[51]Bassett (2014).

personalise a treatment plan with reference to a given patient's individual symptoms, genetics, family and medication history. In critical domains such as health care, algorithmic recommendations, such as Watson's, may serve as inputs to human operators; in other circumstances, algorithms will themselves be responsible for appropriate decision-making. For example, finance is making increasing use of completely automated decision-making. Machine learning algorithms are able to process a greater number of financial announcements and press releases than any human trader, and then act faster upon them.[52] Services like Future Advisor similarly use algorithms to offer personalised financial advice at larger scale and lower cost.

Of course, using big data effectively is no easy task in itself, requiring careful statistical reasoning and informed judgment about what the data can really provide.[53] Nonetheless, the trend is clear: algorithms built upon big data will play an increasingly large role in an ever-growing share of employment.

The increasing availability of relevant big data is in large part due to the digitisation of industries. From traditional banking, to financial services and advertising, digitisation is transforming the world of work. We examine several of these trends in more detail.

Digitisation is Transforming Banks

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The banking sector provides a prime example of how automation is spreading to new domains previously confined to human labour. Automation will continue to be a very important driver of change in retail banking, in banks' back and middle offices in general and on the front end as well. The future of finance is more machines, more mobile interaction, fewer people and more advisory staff.

Digital banking has been a disruptive change to the banking sector and is challenging the traditional bank branch model

One of the biggest changes to the banking sector has been the success of digital banking, which has resulted in a marked behavioural shift. Certain banks have identified that branch transactions have seen a 30% drop since 2010, while other banks have indicated that over half of all consumer lending is now transacted without the customer ever visiting a branch. As a result, the traditional branch model continues to come under review, with the possibility of large cost-savings in both real estate and people. A global comparison of bank branch density (branches per 100,000 population) demonstrates the magnitude of the decline in branches over the past decade, reflecting a combination of bank consolidation and the level of adoption of digital and electronic banking in each country (Figure 11).

For instance, Nordic markets have the lowest number of cheques issued per capita among the developed markets, with Germany not far behind. The same markets also have some of the highest debit card usage. Consequently, these markets have the lowest branch density. In contrast, Southern Europe generally screens poorly with a very branch intensive model, especially in Spain and Italy, albeit often these retail branches can be relatively small. Bank consolidation has only recently happened in Spain and is yet to occur in Italy, which remains a fragmented market. The continued move towards digital banking will see branch density continue to fall overall and some geographies look more vulnerable to this trend. While this should increase efficiency for banks, the trend is negative for staff levels.

[52] Mims (2010 June).
[53] Marcus and Davis (2014).

The adoption of digital money can help 220 million individuals enter the formal financial sector, moving $1 trillion from the informal to the formal sector

Citi's Digital Strategy Team in its recent report *Digital Money: A Pathway to an Experience Economy* estimates a 10% increase in the adoption of digital money can help an estimated 220 million individuals enter the formal financial sector. This translates to an additional $1 trillion moving from the informal economy to the formal economy. The Centre for Economic and Business Research (CEBR) estimates that the cost of cash works out to be about 2.8% of the total cash takings by retailers. Based on this forecast, Citi estimates the adoption of digital money can result in over $125 billion in cost savings from cash handling.

Figure 11. Commercial bank branches per 100,000 adults

	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	% Chg
Spain	98.2	100.1	102.7	105.2	104.9	100.3	97.1	89.6	85.1	74.5	-24.1%
Italy	63.5	64.1	65.4	66.7	70.3	67.6	66.5	66.0	64.4	62.0	-2.4%
Switzerland	57.4	56.8	55.6	55.3	53.9	52.7	51.8	50.2	48.8	48.0	-16.4%
Belgium	57.2	53.7	53.4	51.4	49.7	47.9	45.0	43.4	42.4	41.5	-27.5%
France			45.9	44.8	44.5	41.9	41.5	41.2	38.8	38.7	-15.6%
United States	32.5	33.1	33.8	34.6	35.0	35.8	35.4	35.2	35.3	33.9	4.2%
Japan	34.6	34.4	34.1	34.0	33.9	33.9	34.0	33.9	33.9	33.9	-2.1%
Australia	30.7	30.6	31.2	31.4	31.6	31.5	31.3	30.9	31.8	30.7	0.2%
Denmark	50.1	50.2	50.5	51.9	50.5	45.8	40.9	38.7	34.3	30.3	-39.6%
Canada			24.6	24.6	24.5	24.1	24.0	24.1	24.4	24.4	-0.6%
United Kingdom	29.1	28.4	26.5	26.5	26.2	25.6	24.9	24.2	22.2		-23.5%
Hong Kong	23.6	23.2	23.0	23.3	23.6	23.3	23.6	23.7	23.5	23.1	-2.1%
Ireland	35.9	34.6	34.0	33.4	34.1	34.9	28.7	27.7	25.0	23.0	-36.0%
Sweden	23.6	23.6	23.7	23.6	24.0	23.0	22.5	21.7	21.8	21.7	-7.8%
Netherlands	33.7	28.1	27.7	28.6	27.6	25.2	23.0	21.3	19.6	17.4	-48.3%
Germany	21.3	20.2	16.7	16.3	16.3	15.8	15.7	15.5	13.9	14.7	-31.1%
Finland	13.2	14.4	16.9	16.1	16.1	15.0	15.5	15.1	13.6	12.3	-6.9%
Singapore	11.7	11.5	11.1	10.7	10.3	10.2	10.2	10.0	9.8	10.2	-13.4%
Norway	13.1	12.1	12.0	12.3	11.6	10.9	11.0	10.7	9.9	9.1	-31.0%

Source: IMF

Automation in trading is continuing, leading to headcount reductions and improved operating margins

Post-crisis, both regulation and slumping returns have forced banks to take a hard look at each of their trading businesses to look for ways to minimise costs and maximise efficiencies. We believe these forces quickened the pace of automation in both the fixed income and equity markets. While market disclosure is limited, after speaking with industry participants we believe the product automation timeline is quite wide, with cash equities and treasury futures almost fully electronic and cash bonds at the early stages of electronification and still largely voice traded. Below we lay out the percentage of the market that is electronically traded by product, according to a joint report done by McKinsey and Greenwich Associates[54] (see Figure 12). As more trading moves towards a fully automated market, we would expect to see continued headcount reductions and improved operating margins.

The biggest hindrance to wider e-trading adoption is standardisation…

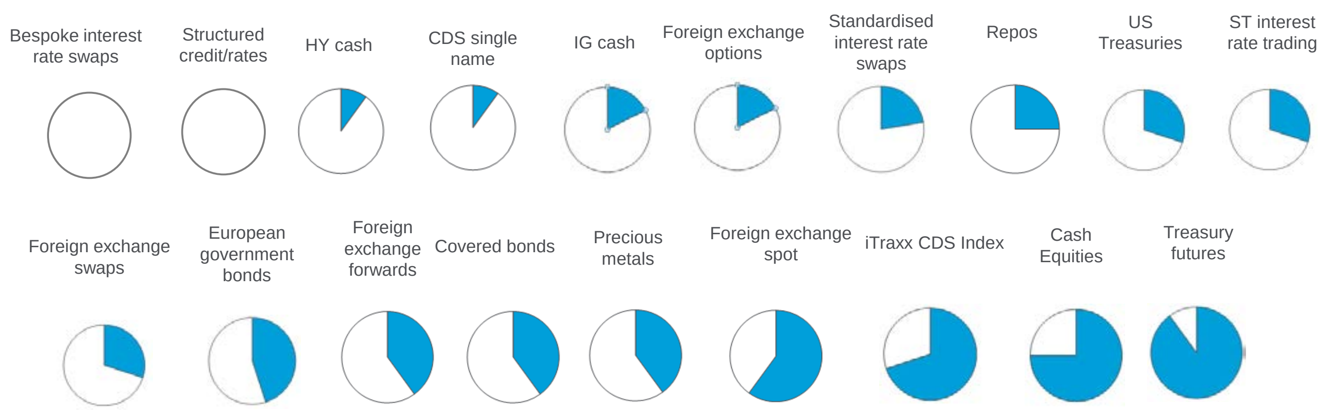
After speaking with market participants, we believe that the biggest hurdle for more markets to move towards automated/electronic trading is the lack of standardisation among products. For example, investment grade and high yield bonds remain largely voice traded, despite significant attempts to create electronic trading platforms. We believe this is largely due to bond market structure, which lacks the standardisation needed to complete a match-based, electronic market like equities.

[54] McKinsey & Company and Greenwich Associates. Corporate Bond E-Trading: Same Game, New Playing Field. Rep. N.p.: n.p., 2013. Web.

…but if this is achieved, fixed income, commodity and currency products may become more 'equity like'

The equity market has taken the largest steps to electronically evolve. After speaking with industry participants we believe that currently ~95% of all stock executions are electronic. This is in stark contrast to only 15 years ago when the majority of stock orders were still traded manually on a physical trading floor. The evolution of the equity market has significantly changed the fundamental economics of the equity business, with machines replacing human traders and costs to trade declining dramatically. According to industry participants, the adoption of electronic trading in the equity markets has led to a 50% headcount reduction over a 10 year period.

Figure 12. Treasury futures and cash equities are largely electronically traded, while cash bonds are at the early stages



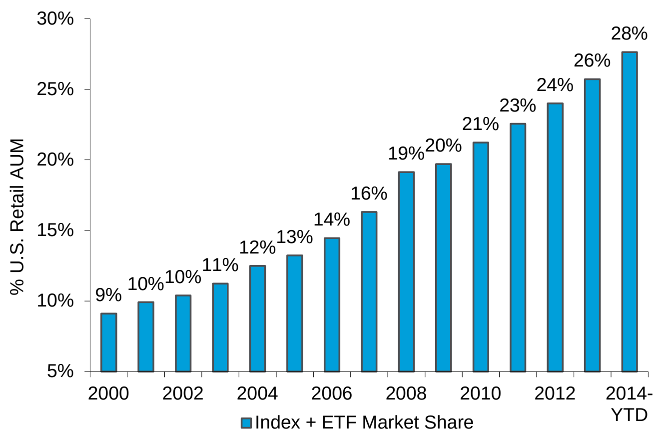
Note: Shaded area represents the percentage of the market that is electronically traded.
Source: Citi Research, McKinsey & Greenwich Associates report

Financial Services Continue to Move towards Passive from Active Investing

William R. Katz
US Brokers & Asset Managers Analyst
Scott T Chronert
US Small/Mid-Cap/ETF Strategist

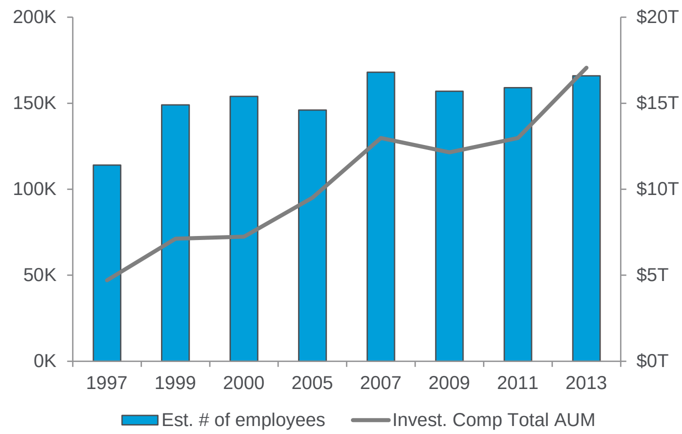
Technological advances have led to the computerisation/automation of many facets of the financial services industry. The emergence of the "exchange traded fund" (or ETF) has, in many respects, been enabled by the evolution of trading technology. Passive and ETF funds now make up 28% of US retail assets under management (Figure 13), up from just 9% in 2000. This shift from active to passive can be seen in the employment numbers of the investment company industry where total assets under management from 1997 to 2013 have grown at a compound annual growth rate of 17.5% while employment over the same period has grown at just 4.8% (Figure 14).

Figure 13. Passive investment market share as % of retail AUM



Source: Citi Research

Figure 14. Investment company industry employment



Source: ICI Factbook 2014

The financial distribution process is helped by automation through the increase in passive instruments such as ETFs

Recently, the Securities and Exchange Commission in the US approved an application for an "exchange traded managed fund' or ETMF. This marks a milestone in the evolution of the mutual fund industry, and provides an interesting application of automation to a financial service distribution process that has been in place for many years.

ETMFs represent "disruptive innovation" to the traditional actively managed mutual fund industry. This arises from their objective to transfer the traditional methods of buying/selling mutual funds to an "exchange traded" instrument. As with other forms of disruptive innovation, we expect an extended time line consisting of early adopters before moving to broader market appeal. Yet, the evolution of passive exchange traded products to a wrapper enabling exchange trading of actively managed mutual funds, and with it, cost savings to the investor derived from efficiencies of an exchange traded approach, provide an interesting application of technology-driven automation into the financial services industry. Not only have ETFs lowered pricing and taken share, the economies of scale of winning funds has also seen share concentration in the hands of a few providers.

Programmatic and Self-Service Shaking up the Digital Advertising Ecosystem

Mark May
US Internet Analyst

Technology is also transforming advertising. In particular, programmatic advertising has become a dominant force in the buying and selling of digital media and we forecast the portion of Internet advertising transacted programmatically in the US to grow at a 4-year compound annual growth rate (CAGR) of 49% between 2014 and 2018. Underlying the increasing adoption of programmatic is marketers' desire to automate the buying and selling of inventory, leverage internal data and cut costs through reduced headcount and a more efficient allocation of ad dollars. With its growing momentum, programmatic has the potential to be highly disruptive to the advertising ecosystem, make other technologies and processes obsolete and reduce the need for human input in the buying and selling of advertising.

What is programmatic advertising and why should I care?

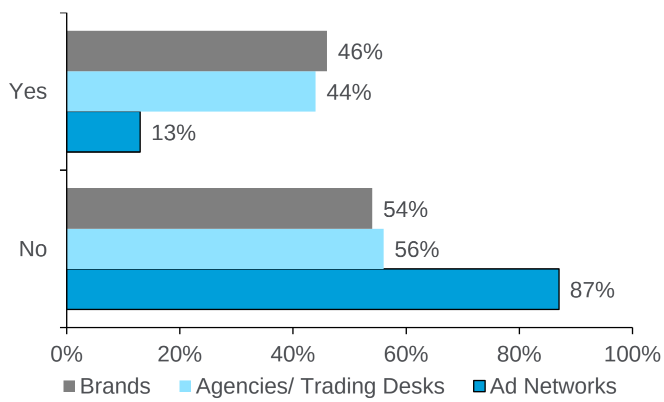
Simply speaking, programmatic advertising is the buying and selling of digital inventory through automated methods of transaction. Traditionally, most media (including digital media) was transacted through a manual campaign-by-campaign request for proposal process that frequently included various advertising parties, slow negotiations and relatively high expense. Programmatic is helping streamline this process through automation, which has resulted in reduced manual input, higher efficiencies, and greater transparency in how ad dollars are allocated. Over the last few years, the adoption of programmatic technologies by brands, agencies, trading desks and other marketers has gained momentum. Citi expects US programmatic spend to be $5.2 billion in 2014 and $25.6 billion in 2018, representing 32% of total US Internet advertising in 2018.

Barriers to implementation

Brand and other marketers are concerned that programmatic is resulting in reduced control over where ads will appear (the right sites and position), whether humans will actually see them (bot-driven traffic) and how post-campaign performance is tracked. Publishers (the suppliers of ad inventory) are concerned about controlling and optimizing the price of their inventory within these programmatic channels, especially for their premium inventory. Over the summer and throughout the fall of 2014, we have seen the AdTech community respond to these concerns. For example, both Google and AOL have acquired ad attribution technologies. Also, TubeMogul and Rocket Fuel announced integrations of third-party protection and third-party reviews to combat fraudulent traffic and issues surrounding brand safety.

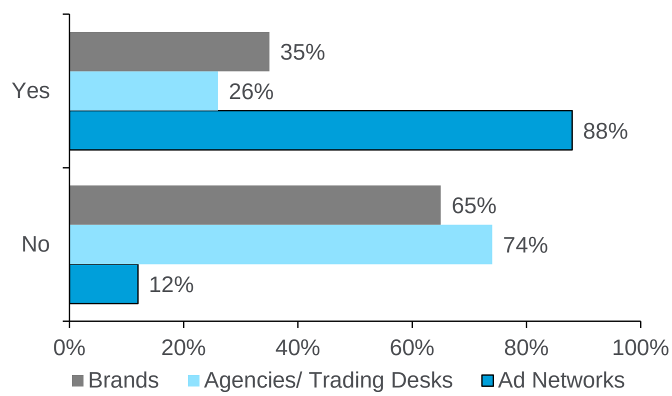
Given its intended benefit of streamlining the buying and selling of media, programmatic represents a disruptive force in the advertising world. We have already begun to see a reallocation of labour at ad agencies and at the advertiser/brands themselves. Figure 15 and Figure 16 illustrate an emerging trend of brands bringing media buying, via programmatic technology, in-house. Out of the 87% of brands currently without in-house capabilities (Figure 15), 88% of them expect to implement in-house programmatic buying technology within the next 12 months. A recent survey by Chango also affirms this trend, with approximately 50% of respondents saying that they will be bringing more of their programmatic buying in-house, while also depending less on agencies. Ultimately, we see human resources at agencies, agency-owned trading desks, and firms heavily reliant on "Direct Sales" as the most exposed to the emergence of programmatic real-time bidding (RTB) and in-house tech. Given these efficiencies, it is no surprise that a self-service salesperson is able to generate client spend 9x greater than that of an assisted-service employee. With brands shifting to in-house programmatic models, we will likely see leaner agencies/trading desks and Direct Sales firms in the near future.

Figure 15. Buyers: Have you bought programmatic video buying technology in-house?



Source: Adap.TV, Citi Research

Figure 16. Buyers: Are you planning on bringing programmatic video in-house within the next 12 months?



Source: Adap.TV, Citi Research

Software: The Mechanism to Automate

Walter Pritchard
US Software Analyst

Within IT, there is ironically a high degree of manual processes that are being replaced through automation with software. Estimates we've seen suggest labour is between 25-50% of IT spending, depending on industry, maturity of company and other factors. As mentioned above, to some degree automation is helping companies grow incremental capacity in data centres and networks and support for more devices without adding IT headcount. We see this with the move towards the "software defined" infrastructure. A decade ago, nearly all devices and infrastructure elements were manually configured. One way to look at this is the server-to-systems administrator ratio in data centres. Servers require certain maintenance and other tasks to be done, with some human intervention required to do these. While not all servers and environments are created equally and the definition of what an administrator does is not consistent, the trend on this ratio has continued to increase. Ten years ago, less than 10:1 was common with x86 (Intel) servers. Today this number is in the 50:1 ratio with many IT shops, while some push 100:1 with high degrees of automation. There have been some press reports suggesting that in web scale environments, with a high degree of server homogeneity and automation, this ratio can be above 1,000:1. There are analogous comparisons around other devices (e.g. storage and network devices) and processes (e.g. level 1 IT support) within IT that can have the impact of pressuring lower skill IT jobs. We note this is unlikely to have an impact on high-skill IT jobs such as software development, where automation is in the early stages or non-existent.

Another area where low-skill customer-facing jobs are facing pressure is customer service automation technologies which drive efficiencies by enabling companies to scale operations without support personnel or outright cut headcount. Examples of these include Internet-based chat support, user self-support, diagnostic technology and modern call centre software.

Digitisation and the Services Industry

Ashwin Shirvaikar, CFA
US Computer Services & IT Consulting Analyst

People and their talent form the basis of the Services industry (both IT and Business Process Outsourcing). Traditional industry contract structures have dictated that most Services work is done and billed for on a per-person, per-unit-of-time basis. The billing rate generally depends on the complexity of work, the location of the worker, the expertise of the worker and the supply/demand dynamics of the specific labour classification.

Technology has both helped and hurt the Services industry

Against this backdrop, automation has long been a factor that has helped as well as hurt growth in the Services industry. Services companies, in their role as technology and process experts, clearly bring productivity benefits to their clients – this is a crucial selling point for their services and has been an important driver of growth. Of course, when Services companies use automation, a portion of the productivity gain is passed onto the client, which creates a headwind of growth to the industry. A second headwind is the deployment of automation directly by the client, which reduces the Services industry's total addressable market. Often, such direct client deployment is due to the availability of software or online/mobile web/app-based solutions. In other words, other parts of the technology industry stack impinge on the Services opportunity.

We believe low- and mid-level jobs in the Services sector that involve repetition are at the highest risk of being lost

Given continuing developments in the area of automation, software is increasingly capable of performing tasks that humans have historically done. When applied to the workforce, we believe that low- and mid-level jobs in the Services sector that involve repetition (e.g. data entry, legal discovery work done by paralegals; journal entries done by accountants) are at the most risk of being lost. This is obviously problematic for the people currently doing these jobs. However, from a societal standpoint, we note the issue is that the “knowledge” workers that lose jobs are typically above-average wage earners, which can obviously have negative derivative consequences. According to work done by Carl Benedikt Frey and Michael Osborne, 58% of Office & Administrative Support occupations are at risk of automation.

Although these numbers sound dire, we note that certain “human” attributes are unlikely to be replicated in the near term. Humans can be empathetic; humans exhibit judgment; strategy and management are in the realm of humans. Asking the right question is easier for humans. Certainly the early implementations of “robotic process automation” systems immediately removed all exceptions processing to a human counterpart. Of course, humans have to design the software as well. But we do sound a note of caution here as well as the fact that the concept of judgment is an interesting one. AI-based self-learning systems can draw conclusions based on data and they can improve over time as more data is presented to them. So, as “data expertise” grows, does the importance of process and domain expertise diminish?

The Services industry will need to adapt from a full-time equivalent-based industry to an outcome-based one

We believe there is still a role for Services professionals in many situations, even if this is a different role from the present time. For Services vendors, the choice is simple – “If you can’t beat them, join them”. There are already examples of companies such as Accenture, Cognizant, EXL Service, Infosys, WNS and Genpact, who have been investing in the development of end-to-end platform-based systems that derive from their knowledge of the underlying process and (sometimes) technology. We believe this is crucial for the future as the Services industry changes towards an outcome based model.

The Internet of Things and Advanced Sensors

A sensor is a device that detects events or changes in quantities and provides a corresponding output, generally as an electrical or optical signal

Driving the rise of big data is the increasing instrumentation of our physical environment. Take the ‘Internet of things’ (IoT), the label given to the connection of embedded computing devices to the Internet. Smart sensors might be installed around a building in order to give detailed and timely readings of air temperature and quality, or attached to goods in a warehouse to enable automated inventory control. The rise of the IoT, and the increasing sophistication of associated sensors, has made such sensor data one of the most prominent sources of big data.[55] Gartner highlights IoT as the most hyped technology of 2014[56] and predicts that 26 billion IoT units will have been installed by 2020.[57] Further, the 2014 EMC Digital Universe study[58] estimates that the IoT generated 2% of the digital universe available in 2014, while forecasting that that figure will increase to 10% by 2020.

Sensor data is often coupled with new machine learning fault- and anomaly-detection algorithms to render many tasks computerisable. A broad class of examples can be found in condition monitoring, asset management and novelty detection, with technology substituting for closed-circuit TV (CCTV) operators, workers examining equipment defects and those responsible for plant control or factory monitoring. GE announced that its IoT software business, which uses sensors to monitor locomotives, wind turbines, gas turbines and oil and gas equipment, will be worth $1.1 billion in 2014.[59] With the IoT allowing for the remote

[55]Ackerman and Guizzo (2011).
[56]Gartner (2014a)
[57]Gartner (2014b)
[58]IDC (2014).
[59]Hardy (2014).

monitoring of equipment and infrastructure, and with algorithms able to identify anomalous conditions, installation, maintenance and repair jobs are becoming increasingly automatable.

Sensors have improved the monitoring of people in health and workplace scenarios

Perhaps more profound are the implications of using the IoT to improve the monitoring of people. Particularly relevant are recent innovations in wearable devices such as the Apple Watch and FitBit Surge, which are equipped with increasingly sophisticated sensors capable of measuring heart rate and activity levels. Healthcare occupations will be affected by such sophisticated sensors and algorithms, including the clinical staff responsible for monitoring the state of patients in intensive care. Remote health monitoring may decrease the need for hospitals and attendant workers, with technology allowing some patients to stay at home, with their anomalous health conditions identified by machine learning algorithms. The comprehensive monitoring of consumers with wearables may allow stores to further automate retail. For example, a business may use heart rate measurements to assess a customer's emotional reaction to the product they have just picked up (as detected by the sensor on the product) and, depending on the assessment, then use the wearable device to make product recommendations. Employees equipped with wearable devices would also be much more thoroughly monitored than is currently possible, enabling employee compensatory schemes that are much more difficult to 'game'. Similar devices, again reliant on machine learning techniques to identify anomalies, might allow also for further automation of fraud detection and tax evasion.

Advances in machine learning technologies have directly contributed to the growth of wearables

Advances in machine learning technologies have directly contributed to the growth in wearables by permitting improved user interfaces. In particular, intelligent user interfaces that can understand a wider range of user intentions are enabling smaller and more intuitive devices. For example, the predictive text capabilities of companies such as SwiftKey can correct for user's typing mistakes by learning their distinctive patterns of writing. Apple's Siri and Google Now use intelligent software to recognise spoken words, interpret their meanings, and act on them accordingly, even in the presence of ambient noise. These technologies allow a more efficient means of obtaining rich data from a human user, enabling automation by better access to human tacit knowledge. Moreover, these technologies may directly substitute for occupations requiring human interaction. For example, a company called SmartAction now provides call computerisation solutions that use advanced speech recognition software that have realised cost savings of 60% to 80% over an outsourced call centre consisting of human labour.[60]

The IoT finds significance in that the volume of rich, heterogeneous data it delivers will better allow algorithms to understand and influence the physical world. This is in contrast to most current sources of big data (e.g. e-commerce), which are relevant only to our digital behaviours. Increasingly intelligent algorithms can hence be brought to bear on the automation of the many jobs that involve interacting with our physical environment.

Sensors are Driving Automation

Jim Suva, CFA
US IT Hardware & Supply Chain Analyst

Arthur Lai
Asian Display and Touch Panel Analyst

Manufacturing has continued to adapt — first shifting to low-cost labour, then to tax holiday havens, and now to lowest landed total costs (a mixture of shipping, labour, taxes, real estate, etc.) — all the while embracing technology innovation of which sensors and connectors have become increasingly important.

[60] Canadian Automobile Association (2012).

Sensors are one of the most important parts for modern factory automation systems. Contemporary industrial automation systems rely on intelligent sensors (not only for monitoring and measurement, but also analysis) connected via low-latency and real-time networks to high-performance programmable logic controllers and human-machine interface systems. With the reliability brought by advanced sensing technology, industrial automation systems are able to reduce labour costs and have transformed electronic manufacturing for many industries (i.e. surface mount technology in electronic manufacturing which place hundreds of parts together in seconds and robotics in automobile production, both of which have historically used a meaningful amount of manual labour while at the same time increased quality and lowered defective rates).

Sensors have not only improved industrial manufacturing processes but also have expanded to consumer items

In addition to the industrial manufacturing process to ensure/improve quality, sensor applications have expanded to consumer items like cars. Auto-use sensors are the eyes of electronic systems, monitoring information inside and outside the vehicle. There are more than 20 types of sensors in today's automobiles with fuel economy and emission regulations leading to engine oxygen and nitrogen oxide sensors becoming commonplace. We estimate growth of total automotive sensor content with a weighted compound annual growth rate (CAGR) of +10.8% from 2008 to 2013 and annual average sensor content growth is forecast at +7-10% versus just over 2% for electronic control units (ECUs).

Robotics themselves require a lot of high quality components such as LED sensors. The high level concept is that automation equipment requires a lot of invisible light sensors (infrared light) to give the robots the correct input. It includes infrared components for integrated ambient light and proximity sensors (ALD). The total market size for infrared sensors likely reached $1.665 billion in 2014, up from $1.461 billion in 2013, a 14% year-over-year increase which is greater than other industrial LED applications (Figure 17).

Figure 17. Infrared-related components (US$ millions)

	2013	2014E
Infrared LED	191	197
Photodiodes	263	269
IrDA Transceivers	54	51
IR Receivers	169	176
Ambient Light Sensor	240	282
Proximity Sensor	14	13
Others	531	6778
Total	1,461	1,665

Source: HIS, Citi Research

Connectors also benefit from the rise in sensors

We also note that connectors will benefit from the expanding application of sensors, as every sensor is connected by a connector and the trend towards wireless connection doesn't mean fewer connectors but potentially more as wireless antennae need connectors for power and transmission. Automotive "electrification" is a driver for connectors as cars become smarter, connected and environmentally friendly. We forecast annual average connector volume growth of 4-6% per vehicle in addition to annual auto production growth of 2-3% less average price declines of 0-2% resulting in organic connector growth of 6-8%.

Intelligent Robotics

Industrial robots have substituted for manufacturing workers for the past three decades

The continued technological development of robotic hardware has long had an impact on employment: over the past three decades, industrial robots have substituted for the majority of manufacturing workers. For example, a typical installation at BMW might use up to 1000 robots capable of handling up to 750kg, performing tasks impossible for humans. In recent years, robots are gaining yet further enhanced sensors and manipulators, allowing them to perform complex manual labour. This is evidenced by the sustained growth in robot sales, which increased in 2014 by 12% year-over-year, a growth rate that is expected to at least continue until 2017.[61] The significance of this for work is suggested by the high "robot densities" in technologically advanced economies: in South Korea, for example, there are now 437 industrial robots to every 10,000 human employees in manufacturing.[62]

New advances in technology will allow robots to be used in new sectors and capabilities

In addition to existing uses in manufacturing, advances in technological capabilities, along with declining costs, will make entirely new uses for robots possible. For example, robots are beginning to be used for a diverse range of professional service tasks, with sales continuing to grow for milking robots, robotic fencers, mobile barn cleaning robots, underwater robots and medical robots for assisted surgery. Defence applications (e.g. mine detection, reconnaissance and surveillance) are a particularly strong driver, with Visiongain estimating the UGV (unmanned ground vehicle) market at around $700 million, and The Economist estimating the UAV (unmanned aerial vehicle) market at around $3 billion. Decommissioning industrial facilities is another growth area for robotics, with an estimated market of £13.5 billion ($20.3bn) for robotic decommissioning at the UK nuclear facility Sellafield alone. A particularly important application for robotics development is in entertainment and leisure as toys and hobbies, e.g. LEGO® Mindstorms®, where novelty is valued and performance requirements may not be exacting. The market for entertainment and leisure robots was valued at around $900 million in 2013. Even more extraordinary growth is being achieved in the use of robots for personal and domestic purposes, with sales up 28% in 2013 versus 2012.[63] Such robots are finding use for vacuum and floor cleaning, lawn-mowing and in providing assistance to those with disabilities. It is clear that, with improved sensors, robots are capable of competing with human labour in a myriad of tasks.

In this section, we examine the expanding scope of robotisation beyond manufacturing, including applications in the defence, healthcare and consumer services markets.

The Effect on the US Defence Industry

Jason Gursky
US Aerospace & Defence Analyst

The military provides a prime driver of recent developments in intelligent robotics. The use of robots by militaries across the world continues to increase as countries seek ways to remove soldiers from harm's way and to garner better intelligence, surveillance and reconnaissance capabilities. In fact, the United States, whose defence budget represents roughly half of the world's total, saw its unmanned aircraft spending grow 14x between 2000 and 2014, driven by the wars in Afghanistan and Iraq.

[61] International Federation of Robotics (2014).
[62] ibid
[63] ibid

Unnmanned systems continue to garner government budget support worldwide

Going forward, we expect unmanned systems to continue to garner government budget support worldwide, particularly in the US, which is seeking to create a smaller, more agile and more technologically advanced military, as a way to reduce the long-term structural cost of soldiers. Not only do unmanned systems address the cost side of the equation, but they can also be more effective given their size, speed and persistence. Funding isn't linear due to post-war drawdowns, but the US military continues to focus on this growing technology.

Figure 18. US Department of Defence systems funding (US$ millions)

$m	2014	2015	2016	2017	2018	CAGR
Air	3776	4819	4468	4217	4419	4%
Ground	13	47	44	54	66	50%
Maritime	330	410	409	430	382	4%
Total	4119	5274	4921	4700	4867	4%

Source: US DoD Unmanned System Integrated Roadmap (FY2013-2038)

Current market participants such as Boeing, Lockheed Martin, Northrop Grumman, Raytheon, General Dynamics, Textron, BAE, etc. are all likely to be the key providers of military robotics given their product portfolios and experience in developing new military systems. However, it is difficult to make an investment case based solely on robots given the propensity of governments, particularly the US, to insert ever higher levels of technology into force structures. Robots are a part of that story, but not a big enough part of it to make a structural difference for any one company. Rather, the broader trend of technology insertion matters most, with the US projecting to spend more on weapons vs. overhead going forward.

Figure 19. US Department of Defence Base Budget (US$ billions)

$b	2014	2015	2016	2017	2018	CAGR
Weapons	155	154	178	181	185	5%
Ov erhead	341	342	358	362	366	2%
Total	496	496	535	544	551	3%

Source: US DoD

Below, we outline the most common uses of unmanned systems and robots in the US military and the products that deliver those capabilities. We note that intelligence, surveillance and reconnaissance (ISR) is the most common use-case for unmanned systems.

- **Air** – Represents > 90% of US spending, with current generation unmanned air platforms used for air strike (MQ-1B Predator, MQ-1C Gray Eagle, MQ-9 Reaper) and ISR (Puma, Wasp, Raven, Scan Eagle, RQ-5 Hunter, RQ-7 Shadow, RQ-4B Global Hawk).

Figure 20. Various unmanned air platforms

Source: Wikipedia

- **Land –** A wide variety of systems for ISF, route clearance, transport and attack. There are no major identifiable platforms, although videos of human/animal-like robots being studied for their transportation capabilities are popular.

Figure 21. Gladiator

Source: US Defense Department

- **Sea –** Often overlooked, unmanned maritime systems are used above and below the surface for ISR, mine-hunting and strike.

Figure 22. Silver Marlin

Source: Military Technology

Ethical and Legal Considerations of Military Automation

Dr Alex Leveringhaus
James Martin Fellow
Oxford Institute for Ethics, Law and Armed Conflict, Oxford Martin School

Automation within the military is increasingly significant, and particularly controversial. It is easy to see why automation is attractive to the military; it potentially increases the speed of warfare, allows fighting from greater distances and shields soldiers from physical harm. Military automation is not a new phenomenon; automated missile defence systems have existed for over half a century. Remotely Piloted Air Systems (RPAS), often known as 'drones', are already partially automated in their flight and surveillance functions.

Yet with advances in Artificial Intelligence programming techniques, the automation of military systems could become more sophisticated in the future, raising concerns about the legality of automated systems as well as their compatibility with fundamental ethical principles. In RPAS, for instance, it might be possible to further reduce the role of the pilot to a point where an operator merely pre-programmes the machine so that, once deployed, it can carry out a mission independently.

Concerns on military automation revolve around the extent to which the automation of targeting processes is legally and ethically defensible

The debate on military automation primarily concerns the extent to which the automation of targeting processes is legally and ethically defensible. For a legal and ethical assessment of automated military systems, it is important to draw three distinctions. Firstly, it is crucial to distinguish between military systems that are classifiable as weapons — meaning that they have been designed to carry and deliver a 'payload' aimed at a specific target — and those that are not. A bomb disposal robot, for example, could be automated to a high degree, yet it is not designed to apply force to a target. Secondly, within military systems classifiable as weapons, it is vital to distinguish between the automation of functions that are not directly related to targeting and the automation of targeting functions; the flight functions of an RPAS could be automated, but this does not mean that its targeting functions should also be automated. Finally, it must be recognised that the automation of targeting functions is a complex undertaking. It is important to distinguish between the partial automation of the targeting process and automation of the whole targeting process.

Automation of targeting processes is not illegal, but it must be shown that the weapon can identify the correct target

It is noteworthy that the potential automation of targeting processes is not illegal. Nevertheless, the legal threshold for the deployment of a weapon with automated targeting functions, especially when these are fully automated, is high. In particular, it must be shown that its deployment complies with the principle of distinction, which obliges individual combatants, and belligerent parties in general, to distinguish between legally legitimate and illegitimate military targets; in other words, it needs to be shown that automated weapons can adequately, and with a high level of certainty, identify the correct target. Morally, robotic weapons are not unethical in themselves, but their development and deployment raises a number of substantive ethical concerns, for example relating to justifications for killing in warfare. While a legal ban and a moral consensus on automated weaponry is unrealistic, policymakers must ensure that the development and deployment of such weapons occurs only within carefully restricted contexts.

Opportunity in Healthcare

Justin Morris
European Med Tech & Services Analyst

Atif Malik
European Semiconductor Analyst

Robots are already being used in a variety of healthcare applications. Robotic surgery will make new forms of minimally invasive surgery possible, which could reduce patient scarring, rehab time, post-surgical complications and deaths. Intuitive Surgical is the leading supplier of robot assisted surgical systems, while Hansen Medical also specialises in robotic surgery. In 2013 there were 523,000 surgeries performed using Intuitive's da Vinci Surgical System (the majority of procedures being in the areas of gynaecology and urology) on an installed base of >3,000 machines worldwide (>2,000 in the US), compared with only about 1,000 robotic surgeries worldwide in 2000.

Robots are already being used in surgery, but not without controversy

The use of robotics in surgery has not been without controversy, with some studies cited in the Wall Street Journal actually finding an increase in adverse events with robotic surgery and questioning whether the potential benefits of robotic surgery outweigh the additional costs given that the price of the systems range from $0.9-$2.5 million, with additional consumables of $700-$2,300 needed for each procedure, according to Intuitive. However, a study published in the February 2015 issue of *Health Affairs,* found that in terms of quality-adjusted life-years gained, the benefits of robotic assisted partial nephrectomy surgery for kidney patients outweighed the healthcare and surgical costs to patients and payers by a ratio of five to one.[64]

In the field of medical robots, advances are aimed at creating a seamless connection between humans and robots such that robots can assist in human functions. Japanese company Cyberdyne, with its hybrid assistive limb (HAL) device, uses an exoskeleton with sensors to detect electrical signals from the body and helps transmit these to the brain, helping people suffering from paralysis to walk again. Citi's Hidemaru Yamaguchi suggests HAL can be used for numerous neural and muscular disorders, including stroke, which affects up to 25 million patients globally, Parkinson's disease (4 million people) and multiple sclerosis (2.5 million).

Brooks Automation's Life Sciences division provides automated sample management platforms for biologic sample storage in a controlled environment and automates the process of retrieving specifically selected samples from within the storage containers. The automated controlled storage environment ensures that samples are preserved within a narrow temperature band to maintain sample integrity (manual retrieval has an increased rate of degradation due to temperature fluctuations, as more samples than needed are typically removed at one time to find the correct sample) and provide absolutely accuracy in the identification and selection of samples during storage and retrieval (manual retrieval has a 10% error rate).

[64] Intuitive Surgical press release.

As automation increases in the biological sample storage market, the size of the market is also expected to increase

The current market for biologic sample storage is $500 million (33% is automated), with that number estimated to be $1 billion by 2018 (estimated 40% automated). Brooks currently competes in the -20 to -80 degree Celsius market with machines that can house 1 million samples and there are only 3 competitors and 200 customers. Brooks is currently developing -150 degree Celsius automation machines that could house fewer samples, but would attract 15,000 customers. The -150 degree units requires significant R&D and enhanced technology to ensure that the robotics do not freeze (which occurs at -8 degrees Celsius). Currently, the -150 degree market is 100% manual and Brooks is expected to have robotic prototypes available for delivery in 2015 with revenue generation starting in 2016.

Robots can also be used to assist patients and the elderly in their own homes, thereby limiting the amount of home healthcare that is required and shortening hospital stays as patients can be monitored remotely. From carrying elderly patients to a bed, a bath or a wheelchair and assisting in food preparation, to lifting food and feeding patients and monitoring vital signs, robots are increasingly being used in the home setting. Examples of devices include 1) Riba by Riken, which can carry elderly patients to a bed, a bath or a wheelchair; 2) Twenty One, which helps disabled people out of bed and helps prepare meals; 3) Secom's My Spoon, which can lift food to a patients mouth; and 4) Para, which is a therapeutic robot pet shaped as a baby harp seal that is designed to be a companion to the elderly and responds to touch, stroke, light and sound.

Robots and Automation in Consumer Markets

Robert Garlick
Global Product Head

James Ainley
European Hotels & Leisure Analyst

The last decade has seen the automation of grocery shop check-outs increase and now automation is extending into restaurants. The National Restaurant Association (NRA) suggests there are 13.1 million fast food workers in the US alone. In December 2013 casual dining restaurant chain Applebee's announced that they would have tablets installed at every table by the end of 2014, allowing customers to order and pay the bill at their tables. In October 2014, McDonalds then CEO Donald Thompson told the Wall Street Journal he plans to "make it easier for customers to order and pay for food digitally and give people the ability to customise their orders." McDonalds has started to install touch screens in Europe, eliminating the need for workers to take a customer's order. A robot manufactured by Momentum Machines can assemble a burger with all the condiments in 10 seconds (i.e. 360 hamburgers an hour) and the company says the device could save fast food outlets $135,000 a year in labour costs according to Digital Trends. This also helps reduce employee turnover issues. In China a new fast food robot called "Chef Cui" slices noodles and costs ¥30,000 to buy ($2,000) vs. $4,700 per year for a human noodle chef, according to Associated Press.

The Hotel and Entertainment industries are using automation for customer convenience as well as headcount reduction

Some hotel companies are rolling out mobile check-in and room key access to save on reception staff and improve customer convenience. Marriott is rolling this out to 4,000 hotels starting in 2014. Merlin Entertainment is rolling out virtual queuing in its theme parks to improve customer satisfaction and free up customers to spend money elsewhere in the parks. Virtual queuing allows you to effectively book your slot on a ride using an electronic device or a mobile app. In the meantime, the customer can grab a coffee or go on another ride rather than standing in the queue. Ticket clerks have also been automated at many cinemas and parking lots. In the travel industry, agents have been replaced by digital travel agents such as Kayak. And when travelling abroad many individuals now use automated gates at passport control.

The Market for Industrial Robotics

Industrial Robotics – Big Opportunity in China, the US and Japan

Graeme McDonald
Japanese Machinery & Shipbuilding Analyst

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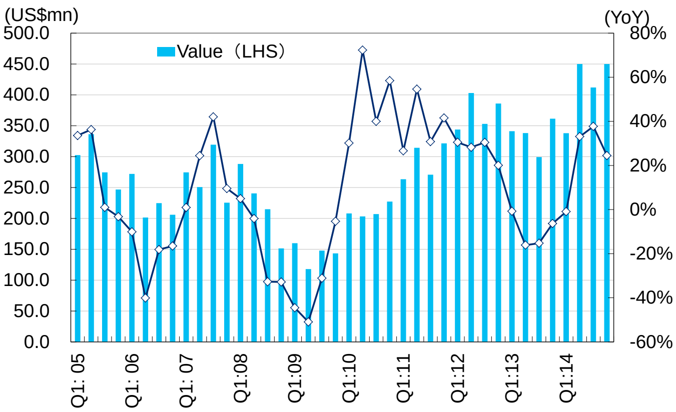
Global manufacturing labour costs today account for $6 trillion annually and further adaptation of automation could represent considerable cost savings; according to McKinsey, in developed countries, across occupations such as manufacturing, packing, construction, maintenance, and agriculture, 15-25% of industrial worker tasks could be automated cost-effectively (based on estimated 2025 wage rates) and in developing countries (on average) 5-15% of manufacturing worker tasks could be automated across relevant occupations by 2025. McKinsey estimates a potential economic impact of $600 billion to $1.2 trillion per year by 2015 based on cost savings using the estimated annual cost of advanced robots compared with the annual employment cost of an equivalent number of workers.

Despite rapid growth the adaptation rates of robotics remains relatively low. In the US, for example, only ~10% of companies that would benefit from automated production have installed any robots so far

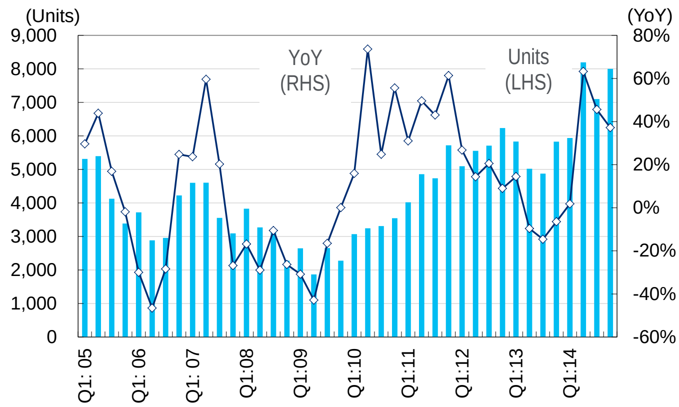
Industrial robotics in particular has been one of the higher growth segments amongst automation. However, despite the rapid growth, the adaptation rate of robotics world-wide remains relatively low. The Robotic Industries Association (RIA) estimates that only ~10% of US companies, for example, that would benefit from automated production have installed any robots so far. Figure 23 and Figure 24 show the value and volume of shipments of robotics in North America and we see an ample opportunity for continued investments in this field.

Figure 23. Value of robot shipments in North America



Source: Citi Research, Robotic Industries Association

Figure 24. Volume shipments of robots in North America



Source: Citi Research, Robotic Industries Association

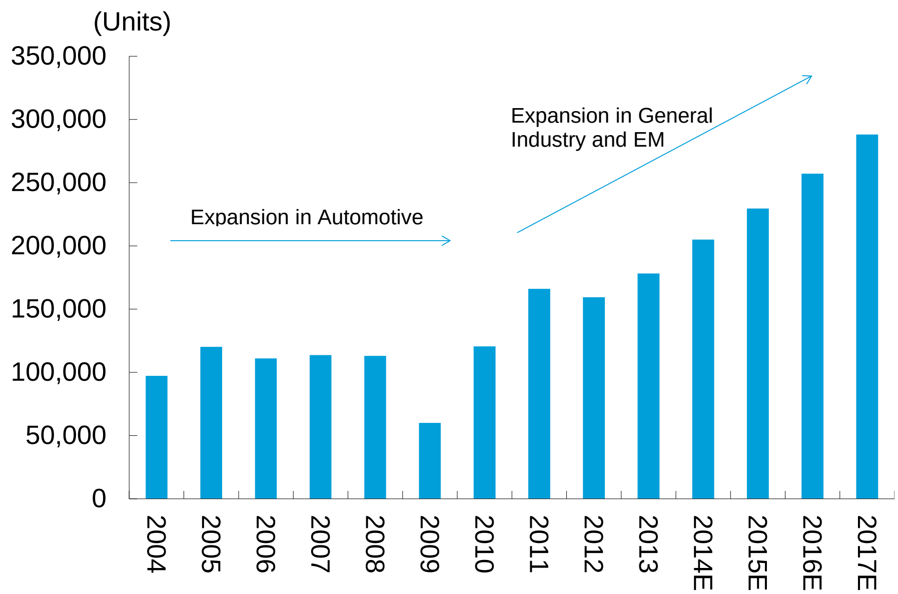
By 2025 there will be 25 million industrial robots sold worldwide, up by 15 million, growing at an average annual growth rate of 25-30% from 2013...this will require investments totalling about $900 billion to $1.2 trillion

According to McKinsey, the number of industrial robots installed globally by 2025 will rise to 25 million, up 15 million from the current level, implying 25% to 30% average annual growth in robot sales, which is considerably higher than the average growth rate over the past two decades. This in turn would require considering investments totalling about $900 billion to $1.2 trillion. It is worth noting that McKinsey's definition of industrial robots is much broader than the one presented by the International Federation of Robotics (IFR). The IFR which tracks units of industrial robots sold globally, measures articulated, SCARA, cylindrical, parallel and linear robots. Therefore the size of the addressable market differs considerably.

IFR forecasts the industrial robotics market to grow by 12% per year to 2017 compared to an average annual growth rate of 10% during 2000-2013 (vs. GDP at 2.3% and industrial production at 3% over the same period)

The IFR forecasts the market to grow by 12% per year to 2017 (Figure 25). This compares to an average annual growth rate of 10% during 2000-2013 compared to an average growth of global GDP of 2.3% and Industrial Production of 3% over the same period. In recent years there has been a clear acceleration of growth, with double digit growth rates (for example 40% year-over-year growth in 2011). In terms of the number of units, the IFR estimates 298,000 units will be sold in 2017 compared to 98,000 units sold in 2000 and 166,000 units sold in 2011. In terms of the sales value, (according to the IFR), in 2013, the sales value increased 12% to $9.5 billion. Including the cost of software, peripherals and systems engineering, the actual robotic systems market value is estimated to be $29 billion.

Figure 25. Annual supply of industrial robots, 2000-2017E



Source: IFR

China is rapidly becoming the largest and fastest growing market for industrial robots, estimated to grow by 25% CAGR during 2014-2017 (vs. 15% CAGR during 2011-2013)

There is a significant scope for growth in robotics across all geographies, but in terms of the rate of growth Asia (in particularly China) is expected to outpace North America and Europe (Figure 26 and Figure 27). China, in particular, is rapidly becoming the largest and fastest growing market for industrial robots estimated by the IFR to grow by 25% CAGR during 2014-2017 compared to 15% per year between 2011 and 2013. According to the IFR almost 37,000 industrial robots were sold to China in 2013 (of which Chinese suppliers installed 9,000 units), up from 14,978 units in 2010. Despite this growth, robot density in China is still low relative to other countries (only 23 robots per 10,000 employees in China vs. 332 in Japan) and structural drivers of (1) wage inflation, (2) changing demographics, and (3) the need for standardised quality, mean penetration should increase. The European and US markets, where demand is more closely tied with replacement needs, are expected to grow at 6% per year between 2014 and 2017.

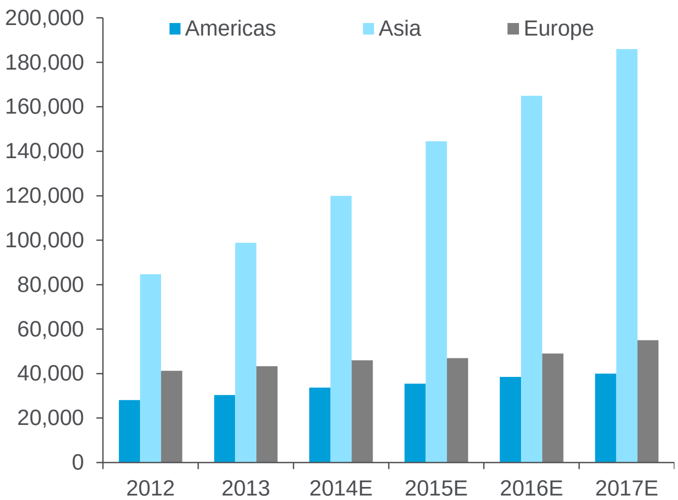
These high growth rates are driven by: (1) increased productivity requirements in developed markets; (2) increasing global competitiveness requirements in emerging markets; (3) the strategic importance of robotics in China; (4) rising wage inflation globally; (5) shortening life cycle of products; (6) declining cost of robotics; and (7) new applications for robotics which are emerging as technology advances.

Figure 26. Industrial robot shipment forecasts by region (units)

	2012	2013	2014E	2015E	2016E	2017E
North America	26,269	28,668	31,500	33,000	35,000	36,000
YoY %		9.1%	9.9%	4.8%	6.1%	2.9%
Brazil	1,645	1,398	2,000	2,300	3,000	3,500
YoY %		-15.0%	43.1%	15.0%	30.4%	16.7%
Other Americas	223	251	200	200	500	500
Total Americas	28,137	30,317	33,700	35,500	38,500	40,000
YoY %		8%	11%	5%	8%	4%
China	22,987	36,560	50,000	70,000	85,000	100,000
YoY %		59.0%	36.8%	40.0%	21.4%	17.6%
India	1,508	1,917	2,500	3,000	4,000	5,000
YoY %		27.1%	30.4%	20.0%	33.3%	25.0%
Japan	28,680	25,110	28,000	30,000	31,000	32,000
YoY %		-12.4%	11.5%	7.1%	3.3%	3.2%
South Korea	19,424	21,307	23,500	24,000	25,000	26,000
YoY %		9.7%	10.3%	2.1%	4.2%	4.0%
Taiwan	3,368	5,457	6,000	6,500	7,500	9,000
YoY %		62.0%	10.0%	8.3%	15.4%	20.0%
Thailand	4,028	3,221	4,200	5,000	6,000	7,000
YoY %		-20.0%	30.4%	19.0%	20.0%	16.7%
Other Asia/Australia	4,650	5,235	5,800	6,000	6,500	7,000
Asia/Australia	84,645	98,807	120,000	144,500	165,000	186,000
YoY %		17%	21%	20%	14%	13%
Czech Republic	1,040	1,337	1,800	2,000	2,300	2,600
YoY %		28.6%	34.6%	11.1%	15.0%	13.0%
France	2,956	2,161	2,300	2,400	2,600	2,800
YoY %		-26.9%	6.4%	4.3%	8.3%	7.7%
Germany	17,528	18,297	19,500	19,500	20,000	21,000
YoY %		4.4%	6.6%	0.0%	2.6%	5.0%
Italy	4,402	4,701	4,800	5,000	5,200	5,500
YoY %		6.8%	2.1%	4.2%	4.0%	5.8%
Spain	2,005	2,764	3,000	3,500	3,600	3,800
YoY %		37.9%	8.5%	16.7%	2.9%	5.6%
United Kingdom	2,943	2,486	2,500	3,000	3,200	3,500
YoY %		-15.5%	0.6%	20.0%	6.7%	9.4%
Other Europe	10,344	11,538	12,100	11,600	12,100	15,800
Total Europe	41,218	43,284	46,000	47,000	49,000	55,000
YoY %		5%	6%	2%	4%	12%
Africa	393	733	800	850	900	1,000
YoY %		87.0%	9.0%	6.0%	6.0%	11.0%
Not specified by countries	4,953	4,991	4,500	5,000	5,500	6,000
Total	159,346	178,132	205,000	232,850	258,900	288,000
YoY %		11.8%	15.1%	13.6%	11.2%	11.2%

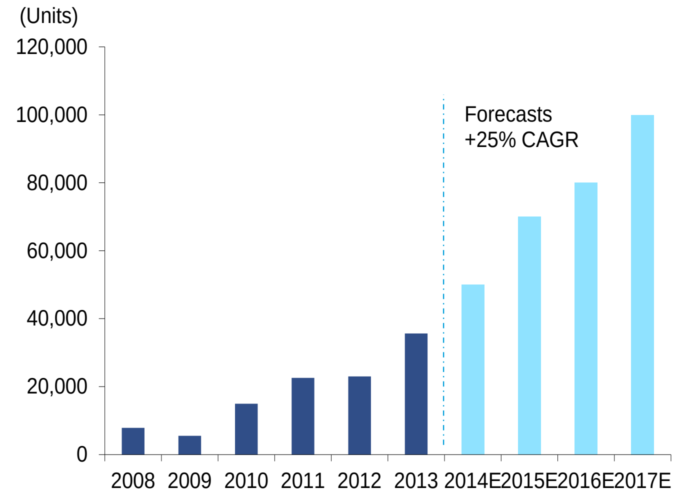
Source: IFR

Figure 27. Annual supply of industrial robots by region



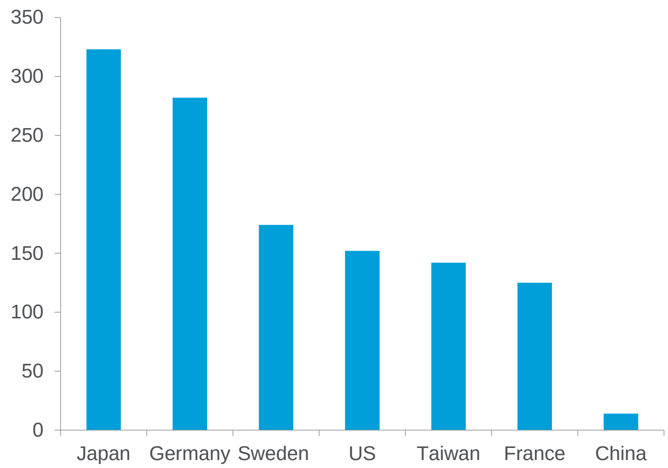
Source: IFR World Robotics 2014

Figure 28. Annual supply of robots to China



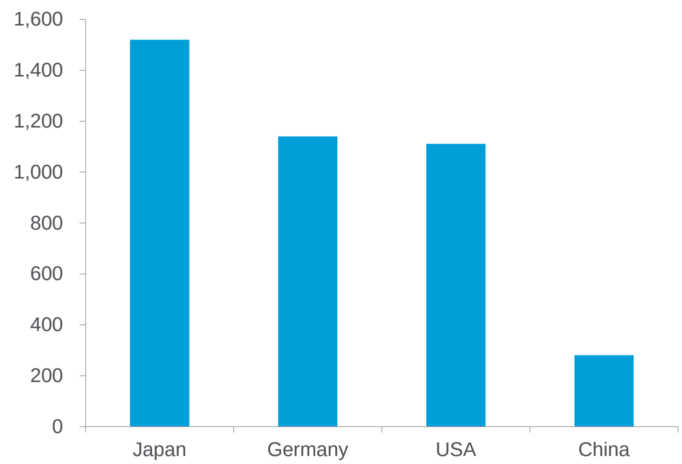
Source: : IFR World Robotics 2014

Figure 29. Total robot density (per 10,000 workers) in 2013



Source: IFR, Citi Research

Figure 30. Robot density (per 10,000 workers) in auto industry in 2013



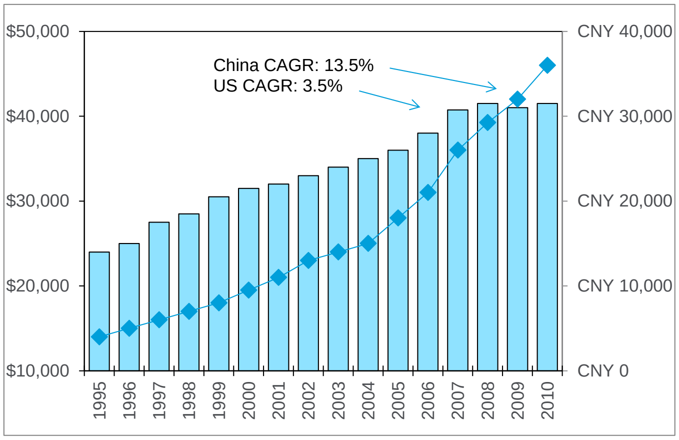
Source: IFR, Citi Research

China Rebalance to Drive Factory Automation Boom

China is showing signs of losing its cost competiveness as labour costs are growing

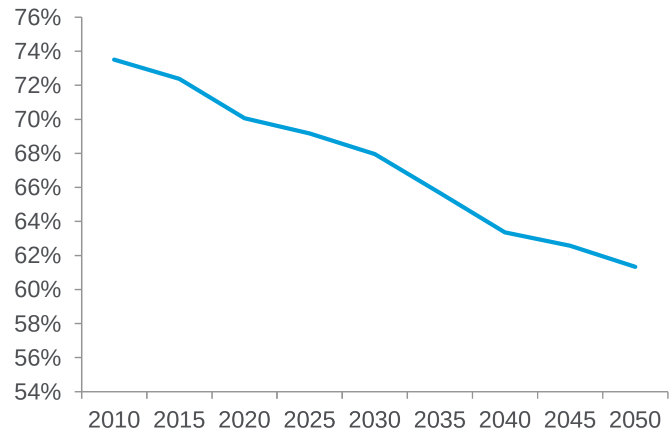
Labour costs in China are rising faster than productivity and Citi's China Economics team believes the country is showing signs of losing its cost competitiveness. China's unit labour cost has been growing since 2000, indicating that average wages were rising faster than productivity, and the pace has only accelerated since then. Meanwhile, labour productivity growth has been decelerating in recent years. In Figure 31, we chart the historical average wage in China vs. the US, along with their 15-year CAGRs. China wages have been increasing at a 13.7% CAGR since 1995, eroding the cost advantage of offshore manufacturing vs. the US, which has only seen 3.5% wage inflation. Meanwhile, the working age population in China is predicted to fall dramatically over the next decades (Figure 32).

Figure 31. US vs. China wage growth



Source: Citi Research, Social Security Administration

Figure 32. China working age population (15-64) (% Total)



Source: World Bank

Automation is a new focus area in China's 12th Five-Year Plan

As a result, automation is a new focus and a new strategic area in China's 12th Five-Year Plan. In a Xinhua report in October 2014, the deputy director of the State Engineering Research Center for Robotics said that there were more than 30 robot factories being built in China, with about 420 so-called "robot enterprises".

China has now replaced the US as the world's largest market for automation and it is expected to maintain its rapid growth. Industry consultant ARC forecasts high growth in a range of Industrial automation segments in China as all being double digit. A different source, GCIS, expects CAGR during 2010-15E to be 16.5% for the whole automation sector in China combined with industrial robotic growth at the fastest rate of around 19%. Drivers of this growth include: (1) rising wages; (2) difficulties in hiring a sufficient number of trained and capable employees; (3) rapid staff turnover; (4) work environment improvements; (5) growth in auto manufacturing; and (6) concerns about a "peaking out" of the workforce.

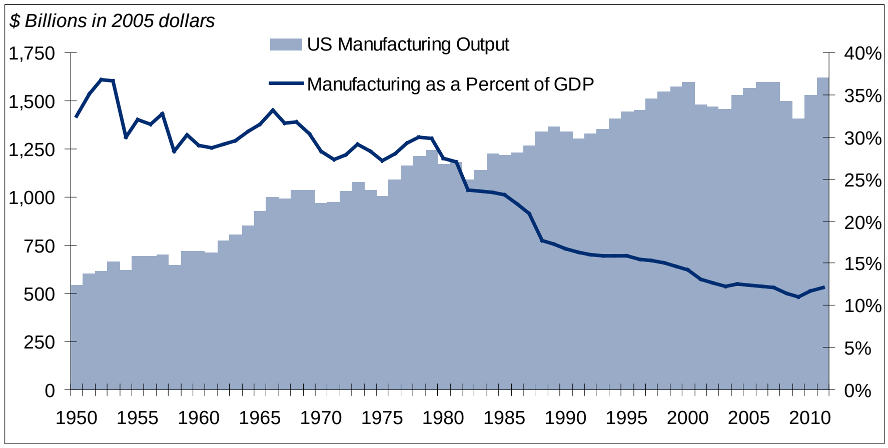
US Manufacturing Renaissance

Could manufacturing within the US economy be bottoming? Manufacturing was once a powerhouse of the US economy, generating roughly a third of total economic output in the early 1950s and 1960s. However, steady erosion has taken place since then, as the US shifted to a more services-driven economy at the expense of manufacturing jobs.

While manufacturing output has been growing in the US, it has fallen as a share of GDP

While manufacturing output in pure dollar terms has grown at a steady pace, the sector as a percentage of national GDP has fallen from over 35% in the 1950s down to around 12% in 2011, illustrating the shift towards a services-driven economy, away from manufacturing and away from US shores. However, the rate of decline has stalled in the past decade, likely having bottomed out and achieved its minimum potential share of the economy. If conditions optimise in the near-term, the US could see a resurgence in the contribution of manufacturing output to total GDP, though it is unlikely that it will ever recover to pre-1980 levels.

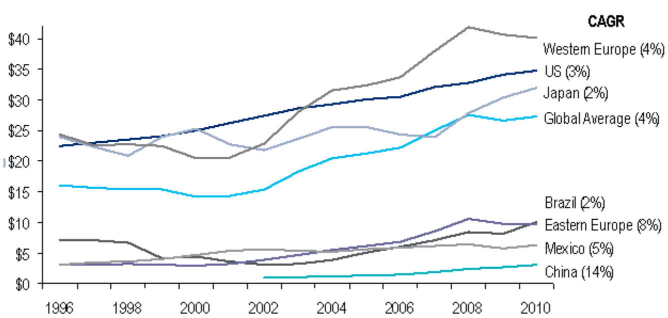
Figure 33. US manufacturing output and its percentage of US GDP



Note: US manufacturing output shown in 2005 dollars.
Source: Citi Research, Bureau of Economic Analysis

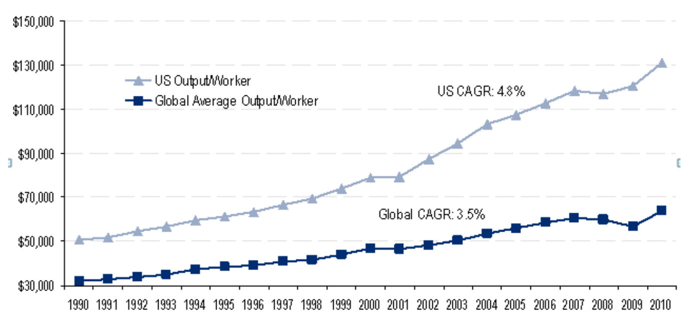
Many manufacturing decisions are driven by the idea that production has essentially become a commodity to be sourced at the lowest cost. The US remains one of the most expensive countries in terms of labour cost, with hourly wages several times higher than emerging market competitors. However, wage inflation in developing countries like China is beginning to erode their cost advantage, though it will likely be at least a decade before wages in these regions reach the levels of developed country counterparts. At a 14% 8-year CAGR, wage inflation in China is steadily eroding its cost advantage. That said, average hourly manufacturing compensation in China is still over 8x cheaper than in the US.

Figure 34. Global hourly manufacturing compensation (USD)



Note: China's CAGR is over 8 years. All other listed CAGRs are for 14 years. The Global Average metric is an average of 19 developed and developing countries around the world.
Source: Citi Research, Bureau of Labor Statistics

Figure 35. US vs global average manufacturing productivity

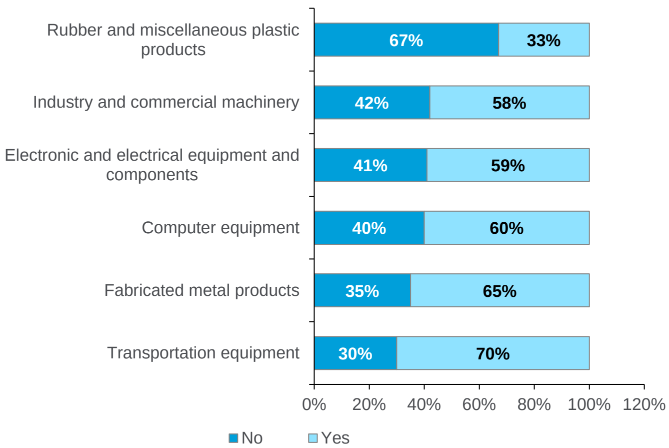


Note: Output shown in 2005 US dollars. Global Average represents mean of developed countries only.
Source: Citi Research, Bureau of Labor Statistics

The US is still leading in terms of manufacturing productivity. When adjusted for inflation, the productivity levels of the US labour force is considerably above the global average and the differential has only widened over time. As developing countries observe their labour costs rise from wage inflation, global manufacturers could begin seeking more efficient and productive workers, a trend that could prove advantageous to the US labour pool. Productivity levels of the US labour force have remained consistently above the global average, and the differential has only further widened over time. Because of this, we believe the US will benefit from reshoring and investment in new manufacturing capacity.

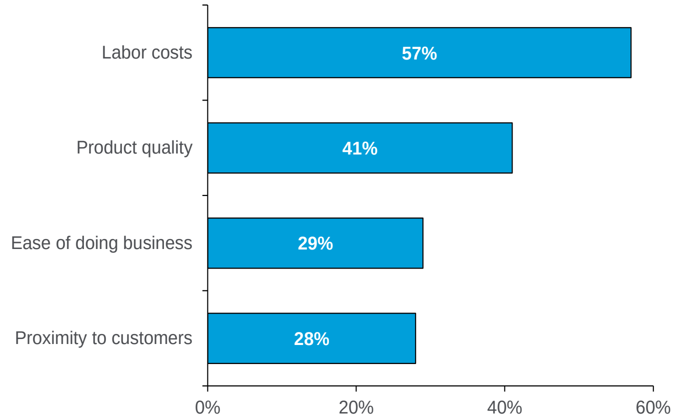
The Boston Consulting Group Manufacturing Survey suggests that more American companies are weighing the decision to manufacture in the US again. Figure 36 and Figure 37 provide a snapshot of the survey published in the Wall Street Journal.

Figure 36. Q: Given the fact that China's wage costs are expected to grow 15-20% per year, do you expect your company will move manufacturing to the US?



Source: Boston Consulting Group Manufacturing Survey, Feb 2012, WSJ

Figure 37. Q: Please rank the most important factors you consider when deciding where to locate production for products consumed in the US



Source: Boston Consulting Group Manufacturing Survey, Feb 2012, WSJ

There have been several recent examples of manufacturing companies reshoring to the US

We highlight in Figure 38 several examples of manufacturing investment in the US from both domestic and international industrial companies. This illustrates the theme of a global flow of capital into the US sector; the new facilities have not only increased the activities of multinational companies within the US, but have also added thousands of manufacturing sector jobs in the country. With this comes an increase in automation and more efficient production resources. There are now ~225,000 operational robots in US-based factories, placing the US second only to Japan in terms of robot use. One driver of the shift to robotics in North America has been the increase in capex investments by automotive original equipment manufacturers (OEM) and component suppliers, which allocate about 50% of their spending on robots. There has also been a growing application of robots in other non-auto industries, such as metalworking and life sciences/biomedical. This notable and broad-based growth in robotic equipment could further increase US manufacturing productivity, though it could come at the expense of manufacturing jobs as more production becomes automated.

Figure 38. Reshoring examples in recent years

Company	Products	Investment	Location	From-To	Year (announced)	Jobs	Reshore/New
Apple	Mac products	$100 mn	Texas, US	China-US	2012		Reshore
Caterpillar	Small construction machinery	-	Georgia and Texas, US	Japan-US	2011	> 1,000	Reshore
Celebriduck	Toys	-	-		2012	50	Reshore
Farouk Systems	Hair Dryers	-	-	China-US	2009	1,500	Reshore
Ford	Cars	$6,200 mn	US		2011	12,000	New+Reshore
GE	Appliances	$1,000 mn	Kentucky, US	China-US	2012	c. 1,000	Reshore
K'nex	Toys	-	Pennsylvania, US	China-US	2020	25-30	Reshore
Lenovo	PC Manufacturing	-	North Carolina, US		2012	100	Reshore
Masterlock		-	Wisconsin, US		2012	100	Reshore
Motorola	Cellphones	-	Texas, US		2012	2,500	New+Reshore
NCR	ATM manufacturer	-	Georgia, US		2009	c. 3,000	Reshore
Nissan	Cars (Sentra model)	-	Mississippi, US	Mexico-US		1,000	Reshore
Oracle	Data centre services & storage systems	-	Oregon, US	Mexico-US		430	Reshore
Philips	Shaver production	-	Drachten, Netherlands	China-Netherlands	2011	-	Reshore
Selected Furniture	Furniture	-	Indiana, US	China-US		40	Reshore
Trellis Earth Products	Bioplastic goods	$8.3 mn	New York, US	China-US	2013	189	Reshore
United Technologies	Elevators	-	South Carolina, US	Mexico-US	2012	360	Reshore
Whirlpool	Small appliances	$40 mn	Ohio, US	China-US	2014	400	Reshore
Whirlpool	KitchenAid hand mixers	-	South Carolina, US	China-US	2012	25	Reshore

Source: Citi Research, Company, WSJ, Huffington Post

Robots and Japan

Japan and its robot industry

Data from the Japan Robot Association (JARA) show that in 2013 the Japanese market for robots was worth ¥402 billion ($4bn). Overall shipment value fell 4% year-over-year, with the biggest drop seen in chip mounters down by 18%. In 2014 we think the market grew by over 20%, to close to ¥500 billion ($4.6bn), with CAGR of more than 10% expected over the next few years, as per volume forecasts made by the IFR. On a regional basis the largest and fastest growing market for the Japanese robot makers is China which now accounts for approximately 25% of total demand with the largest and most significant end user segment said to be the auto industry.

Japanese names also dominate the supply chain

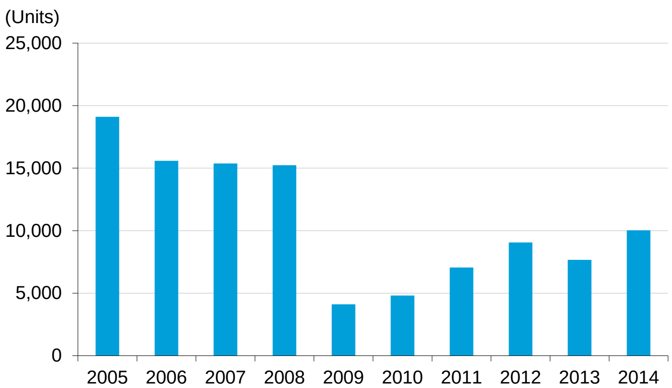
The largest makers of industrial robots in Japan are Fanuc and Yaskawa, with 2014 revenues of about ¥170 billion (+20% year-on-year) and ¥140 billion (+16%), respectively. Other smaller suppliers include Kawasaki Heavy, Nachi Fujikoshi and Daihen. However, we note that industry data from the JARA also includes chip mounters, which do not meet most people's idea of a robot, and it is worth highlighting that revenues at Fuji Machine in 2014 grew by about 5%, to ¥52 billion, with other large mounter makers including Panasonic Factory Solutions, JUKI and Yamaha. On the component side, Fanuc and Yaskawa both use in-house made servo motors and controllers but there are a wide range of Japan-based component suppliers such as Nabtesco (with its 60% share in precision speed reducers); Harmonic Drive (a smaller, niche player in precision speed reducers which is also partly owned by Nabtesco); THK (roller bearings); and Obara (a leading maker of welding guns).

Auto industry is about one-third of demand in Japan, half in the US but maybe three-quarters in China

Including chip mounters, data from the JARA showed that in Japan the auto industry made up ~35% of the value of industrial robot demand in the third quarter of 2014. This is relatively low compared to the US where the auto industry is said to make up about half of total demand. Yaskawa suggest that maybe 70% or more of its total industrial robot shipments are to the auto industry but this ratio is closer to 80% in China. It is quite clear that the challenge for Yaskawa, Fanuc and other robot makers in China is to expand applications in the non-auto industry.

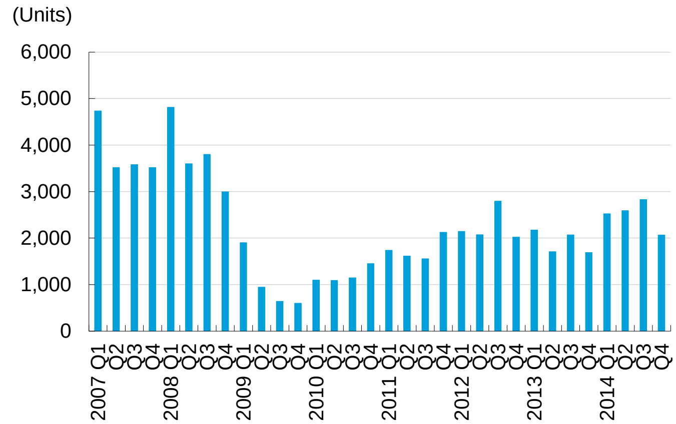
One reason for the relatively low dependence of the auto industry in Japan is the simple fact that current production capacity is over 10 million, while production in 2014 was around 9.5 million units, including exports. As shown below, helped in part by the weak yen, demand for robots from the auto industry has seen a recovery over the past three quarters but on an annual basis demand is still well below the pre-Global Financial Crisis level. At the same time, the domestic auto industry already has one of the highest robot densities globally (1,520 units per 10,000 workers) compared to only 214 in all other industries.

Figure 39. Annual demand for robots from the auto industry in Japan



Source: JARA, Citi Research

Figure 40. Quarterly demand for robots from the auto industry in Japan



Source: JARA, Citi Research

Robots and the workforce

In terms of the impact of robots on employment, the relationship is complicated. Using Yaskawa as an example, visiting their robotics plant in Jiangsu (China) we recently saw a plant where monthly production is being ramped up towards 500 units but there were only a handful of robots being used to tighten screws and in the paint shop. As of late November 2014, the plant employed 190 people and was producing ~320 units/month. However, it is clear that more people will be employed to cope with the expected increase in output. In contrast, the company told us recently that at its new #3 robot plant in Kita Kyushu (Japan) they have managed to reduce workers at one assembly process by about 80% (from 20 to only 2-3), and have re-assigned these workers. Similarly, their dual-arm robots are being used on the assembly line at their domestic servo motor plant in Iruma (Saitama) with the specific aim of reducing higher cost employees.

Autonomous Robots

The coupling of advanced sensors and actuators in industrial robots to create autonomous robots will have profound impacts on employment

Industrial robots are an exciting opportunity, however, it is in the coupling of the advanced sensors and actuators in industrial robots to machine learning algorithms to create autonomous robots that the most profound impact upon employment will be found. Many tasks have remained non-automatable by virtue of the difficulty of encoding the tacit knowledge we hold about how to interact with and manipulate our physical environment. For example, when navigating in a vehicle, we draw upon a rich knowledge of the automotive environment: we recall landmarks, interpret road signs and account for recent changes due to construction or snowfall in order to determine where we are in space. We might even use deep knowledge of culture and society in order to inform our judgment: for example, a dirt track is unlikely to lead to a supermarket, and a bus is most probably heading to or from a major settlement. However, in recent times, this complex tacit knowledge has not prevented the automation of driving: the Google self-driving car was licensed to drive in the US state of Nevada in 2012.

The explanation for how human tacit knowledge was sidestepped is firstly found in the availability of increasingly instrumented vehicles. Mass-production vehicles, such as the Nissan LEAF, contain on-board computers and advanced telecommunication equipment that render the car as potentially a fly-by-wire robot.[65] Advances in sensor technology mean that vehicles are likely to soon be augmented with even more advanced suites of sensors. These will permit an algorithmic vehicle controller to monitor its environment to a degree that exceeds the capabilities of any human driver: they are not subject to distraction, have the ability to simultaneously look both forwards and backwards, and can natively integrate camera, GPS and LIDAR data.

The Auto industry is already using big data and improved sensors to substitute for human workers

The big data provided by these improved sensors are offering a substitute to human tacit knowledge. Firstly, many modern vehicles offer Advanced Driver Assistance Systems (ADAS) that draw upon sensor data to provide adaptive cruise control, automated braking and even automated parallel parking. Further, the use of sensors to create three-dimensional maps of road networks has allowed for the automation of navigation; Google's driverless cars use an array of sensors to gather inch-precision readings of its environment costing over $150,000.[66] On-board algorithms can then compare a vehicle's current environment against prior maps stored on the vehicle in order to determine its location. Modern approaches store maps that characterise the different appearance of the environment throughout all the changing seasons (e.g. after snowfall).[67] Machine learning techniques have also been developed to identify unexpected changes to the road network, such as those due to road construction.[68] Many auto manufacturers are expecting to be able to offer autonomous vehicles between 2020 and 2025.[69]

Given their superior sensing capabilities, algorithms are thus potentially safer and more effective drivers than humans. This is no trivial contribution: road fatalities are within the top 10 global causes of death, with human error responsible for more than 90% of traffic accidents.[70] There are further potential contributions from autonomous vehicles: 20% of carbon dioxide (CO_2) emissions on the road are due to inappropriate accelerations, while 2% of US GDP is wasted because of congestion. If robotic vehicles join the Internet of Things, we can envisage a networked fleet of vehicles whose inter-communication and decentralised planning may be able to tackle these problems.

[65] A fly-by-wire robot is a robot that is controllable by a remote computer.
[66] Guizzo (2011).
[67] Churchill and Newman (2012).
[68] Mathibela, Osborne, Posner, and Newman (2012).
[69] Citi GPS (2014).
[70] ibid

Autonomous Vehicles: Transforming Mobility as We Know It

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Automated vehicles offer potentially wide-ranging societal and business benefits from improved safety, improved fuel economy, new forms of mobility and the unlocking of time spent in the vehicle. As outlined in our report *Citi GPS: The Car of the Future*, a safer and more convenient vehicle will likely become less expensive and more enjoyable to operate. Eventually, fully automated vehicles and new forms of mobility services might allow greater access to cars for consumers who either cannot or do not drive. As cars become connected machines that can "see" and learn, road efficiencies could increase—think high-speed highways. Cars will be able to share their positions, experiences and driving tips with each other. New forms of human-machine interfaces, such as augmented reality, could completely change the way we interact with our surroundings.

Figure 41. Global auto fatality stats

	Fatalities/ 1,000 vehicles
United States	15
Germany	7
Japan	7
South Korea	26
China	36
India	315
Thailand	119
Brazil	71

Source: Autoliv company reports

Despite major advancements in automotive safety systems throughout the past 20 years, road fatalities still claim over 1 million lives around the world each year (Figure 41). In the U.S. alone, annual fatalities top 30,000. The outlook is unfortunately even grimmer considering the aging population and the increasingly connected (i.e. distracted) driver. By 2030, road fatalities are poised to rank in the top 5 causes of death globally. Why should driving be this unsafe?

It is estimated that 93% of US accidents are caused by human error, with Europe sporting a similar ratio. Alcohol remains a major US contributor involving ~30% of fatal crashes. Speeding is also a major factor at ~30%, driver distraction ~20%, lane keeping ~14% and failure to yield ~11%. It is estimated that if a driver is afforded an extra ½ second of response time, roughly 60% of accidents could be avoided or mitigated. So why should driving a car be this unsafe when the root of the problem is concentrated in driver error and impairment?

Key Drivers of ADAS Demand

We see three core drivers of future ADAS demand:

1. Regulations: In terms of regulation, the EU new car assessment program is leading the way by essentially requiring all vehicles to have ADAS by 2017 to achieve a 4-star rating on automatic emergency braking. We expect US regulation to be solidified over the next few years as well.

2. Possible Future Insurance Savings: As ADAS penetration rises and begins to prove out in real-world reductions in claim frequency/severity, the potential for lower insurance premiums might also accelerate ADAS demand.

3. Consumer Value: Safety ranks highly in consumer preference surveys and there is evidence that consumers are willing to pay premiums for a 'value bucket' of ADAS convenience applications – adaptive cruise control, traffic jam assist and soon automated highway piloting.

ADAS Migration to Automated Vehicles

ADAS is moving through different categories depending on the level of automation and driver involvement over the next 8 years

Autonomous vehicles tend to be grouped into categories depending on the level of automation and driver involvement. ADAS tends to be considered Level 1—sensor/software provides assistance but the driver is driving as usual. Level 2 includes things like automated highway piloting where the driver is required to monitor the system as the primary operator of the vehicle even as the vehicle performs autonomous task. This is the next stage that's likely to sweep the industry over the next 1-3 years. Level 3 is full automation where the driver doesn't have to monitor the system but must still be engaged enough to take control after a brief warning (maybe 10 seconds). Think of the car driver playing the role of an airplane pilot. Level 3 is likely 4-8 years away but is already deep into the development process.

Fully autonomous driving is not expected to be a reality until the early/mid-2020s

The final level — Level 4 — is a fully autonomous driverless vehicle. Most expectations peg this becoming reality in the early/mid-2020s. Beyond technical and cost hurdles, driverless vehicles pose challenges from a regulatory, legal and security perspective. There's a healthy debate around Level 3 vs. Level 4 vehicles — will drivers even want to give up the joy of driving? But what about mobility models like driverless tax-speeds (particularly at a safer low-speed) or mileage efficiencies in the fleet as cars start operating without occupants? And what's the cost premium for going from Level 3 to Level 4? It's clearly early to fully tackle all of these questions, but we do believe that there are some compelling use cases for the eventual driverless vehicle, particularly in fleets and 2nd/3rd car replacements. Google's efforts in this area will undoubtedly be monitored closely and in doing so likely establish greater consumer awareness of ADAS and autonomous vehicles.

Figure 42. Phases of automated driving technology

Now	ADAS: A critical line of defence but doesn't drive the vehicle
Leap 1: 1-3 years (2015-2017)	All ADAS + Automated braking, Automated throttle, Automated steering with forward vision and GPS connectivity. Key App = Auto Highway Piloting.
Leap 2: 4-8 Years (2018-2022)	Car can accelerate/brake/steer by itself through transitions, lane changes, intersections, country roads and cities. Drivers operate like today's pilots do; standing by to take over in case of emergency or system failure.
Final Leap: (2022+)	Driverless car. Versus Leap 2/3, key issues relate to legislation, security and incremental cost vs. consumer demand. We see a strong case for low-speed applications like taxis and car-pooling, but the mass adoption case is unclear yet.

Source: Company Reports, Citi Research

Autonomous Robots Outside the Auto Industry

Outside of Autos, autonomous robots will be an important factor in agricultural vehicles, forklifts and cargo-handling vehicles

This emerging technology in automation will affect a variety of transportation and material moving jobs. Agricultural vehicles, forklifts and cargo-handling vehicles are imminently automatable, and hospitals are already employing autonomous robots to transport food, prescriptions and samples.[71] Kiva Systems was bought by Amazon in 2012 for $775 million to automate its warehousing, with the company providing robots able to navigate their way around crowded warehouses. Further, the computerisation of mining vehicles is being pursued by companies such as Rio Tinto, seeking to replace expensive labour in remote Australian mine-sites.[72] If such vehicles become commonplace, they will provide a rich resource of big data gathered by sensors that may have many knock-on effects for employment. For example, law enforcement may be affected by the recordings made by vehicles near crime scenes.

Improved machine intelligence is behind other advances in robotics. Baxter, a $22,000 general-purpose robot, provides a well-known example. The robot features an LCD display screen displaying a pair of eyes that provide an expressive reaction to user input. Baxter is able to learn new manual tasks by having a human worker guiding its robotic arms through the motions that will be reproduced in completing the task. Baxter then memorises the patterns of the motions and can communicate that it has understood its new instructions.[73] OC-Robotics' robotic snake arm is unique in its ability to manipulate and explore cramped environments. However, its flexibility comes at the cost of increased difficulty in control: it is only advances in machine intelligence that permit its application to plant maintenance.

As robot costs decline and technological capabilities expand, robots can thus be expected to gradually replace human workers in a wide range of low-wage service occupations. Alarmingly, it is in these occupations that most US job growth has occurred over the past decades:[74] robotic automation may cause considerable disruption to US employment.

Autonomous Mining

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Head of European Engineering Research

Klaus Bergelind
European Machinery Analyst

Contrary to other sectors such as Automotive, where our Autos team believe that driverless vehicles won't be commercially viable until 2025, autonomous mining equipment is available "here and now", and the incentives to go autonomous are big. Labour is one of the biggest cost drivers for a big miner, contributing to over 30% of a miner's cash cost. There is also the aspect of safety. Not only is this important in itself, but the safest mines are often the most productive. The adoption so far has been slow, with surface technologies only recently commercially viable. Driverless underground technology has been in place since the 1960s, when LKAB's Kiruna iron ore mine in Sweden (considered the world's largest modern iron ore mine) started using driverless underground trains. The presentation of the first fully autonomous drill rig, a year ago, by Atlas Copco and Rio Tinto, added to already autonomous trucks/haulers in surface mining, closing the technology gap further with underground technologies, with now only excavators still in need of manned control. Telematics (condition monitoring) have been in place since the last peak in 2007, monitoring the performance of the equipment to avoid downtime, but the real savings visible is when machines can replace staff, contributing to pure overhead savings but also increasing productivity as autonomous machines move faster, are more precise, and cover longer distances.

[71] Bloss (2011).
[72] Rio Tinto's computerisation efforts are advertised at http://www.mineofthefuture.com.au.
[73] MGI (2011).
[74] Autor and Dorn (2013).

The Numbers – Calculating the Benefit

We can see $1.4 billion of savings from introducing full autonomy into just 10% of existing mining trucks, a meaningful number against total operating expenditure reductions of $8 billion so far and $35 billion of cost headwinds over the last decade

The biggest saving in applying autonomous technologies is undoubtedly through the possibility to cut labour costs, with over 30% of a miner's cash costs stemming from staff. According to online media (Unmanned Systems News, Engineering and Mining Journal), it takes 4-5 drivers to operate a truck 24-hours, but up to 10 people in total once support staff are taken into account. Each driver is paid a salary on average of $120,000 per year, thus around half a billion dollars in cash costs for the operation of each truck (excluding the cost of support). According to an article in Wall Street Daily in May 2014, the population of autonomous trucks today is a mere 0.5% of the 40,500 total global population of trucks. Our discussions with BHP suggest that one-tenth of trucks could be autonomous in the near future, whilst the most bullish comments suggest fully automated mines are a reality within the next 10-15 years (according to Unmanned Systems News and Science and Technology World).

A simple calculation of the benefits just from cutting down staff (ignoring the increase in productivity) looks as follows:

According to a study by Deloitte on the economics of autonomous mining, introducing an autonomous truck could reduce the number of operators by 75%, i.e. 1-2 operators are sufficient instead of 4-5 today. This implies a $360,000 reduction in cash costs, or $1.4 billion in total assuming 10% of the truck population is autonomous (Figure 43). A cost reduction of $1.4 billion is meaningful and compares to about $8 billion of total savings from the majors achieved so far and $35 billion of cost headwinds over the last decade.

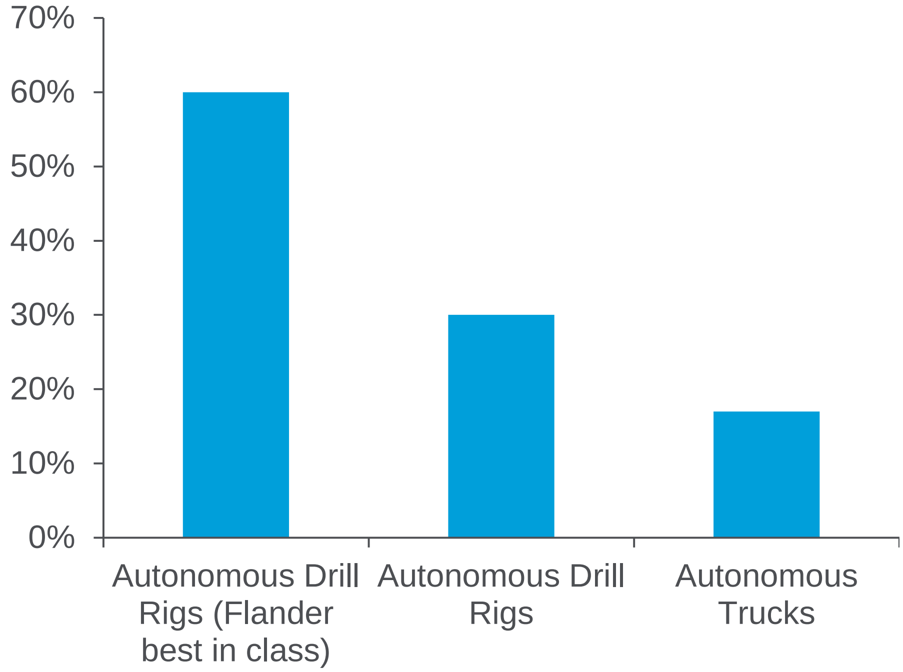
On the productivity gains and other costs such as maintenance, John Meech at the University of British Columbia in Canada presented his findings in the paper "Simulation of Autonomous Mine Haulage Trucks" in 2012, which showed a 15-20% increase in output, 10-15% decrease in fuel consumption and an 8% reduction in maintenance costs, by shifting to autonomous haulers. Compared to autonomous drill rigs, this is interesting, as Sandvik and Flanders have presented figures showing that autonomous drill rigs can increase productivity by near double the level of autonomous haulers — by 30%, and in some cases by 60% when shifting to autonomous drilling (Figure 44).

Figure 43. Implied cost savings by adopting autonomous trucks

	No of drivers per truck	Salary per driver ($)	Cash costs per truck ($m)	Savings per truck ($m)	Truck population (units)		Total savings ($bn)
					Manual	Autonomous	
Today	4-5	120,000	600,000		40,500	203	
Implied	1-2	120,000	240,000	360,000	36,450	4,050	1.4

Source: Citi Research, Deloitte, University of British Columbia

Figure 44. Estimated productivity increase shifting to fully autonomous trucks and drill rigs



Source: Citi Research, Sandvik, Flanders, University of British Columbia

Mine Automation – Today and the Future

The focus today is to build a fully autonomous mining system that can carry out tasks with minimal or no human control. Such development is naturally much more advanced, particularly upstream, as mining machines move around and often in complex and hazardous environments

To date, most automation in the mine has been focused on components and sub-systems and at a relatively small scale to the number of mines and processing plants. The focus so far has been on telematics (condition monitoring) and traditional process automation technologies applied in downstream operations. Telematics have been in place since 2007 across most major mines monitoring the performance of the equipment to avoid downtime. These "asset health" systems generate data onboard the equipment which is streamed wirelessly to evaluators based at the miners' operations centres, who analyse and take steps to maximise the operational effectiveness of individual pieces of equipment. Downstream operations have traditionally been at the centre of mine automation with process automation in crushers, grinders, and smelters in place for the last two decades, and traditional process automation technologies with distributed control systems (DCS) controlling and optimizing the productivity at different plants, and the flexibility of programmable logic controllers (PLCs) also more recently being integrated to offer a more hybrid automation offering.

The focus today is to build a fully autonomous mining system that can carry out tasks with minimal or no human control. Such development is naturally much more advanced, particularly upstream, as mining machines move around and are often in complex and hazardous environments.

3D Printing

"Additive manufacturing", or 3D printing, requires less cost, time and expertise than traditional manufacturing techniques

3D printing, also known as "additive manufacturing", has been around since the 1980s. Relative to traditional manufacturing techniques such as injection moulding or CNC milling, 3D printing is slower, has poorer finish quality and is more expensive per item. However, 3D printing requires less cost, time, and expertise to create a small number of new items and it obviates the need for expensive retooling to manufacture new products. It hence has traditionally found value in prototyping new designs, and for some high-value, low-volume products. The recent significance of additive manufacturing is found in its democratisation and automation of manufacturing tasks. 3D printing is able to make direct use of designs produced using CAD (computer-aided design) software to manufacture even complex geometries, whereas other manufacturing techniques demand detailed expertise to specify tooling paths. With an increasingly networked society, appropriate designs are readily shared or purchased, allowing even non-experts to begin 3D printing. Hence 3D printing provides a connection from the digital world to a flexible means of physical manufacturing, reducing the need for manufacturing workers. 3D printing technologies have recently been extended to produce items in plastics, glass, paper, ceramics and even metal. Growing demand has led to dramatic reductions in the size and cost of 3D printing devices, yet furthering their broad adoption, with printers now available for as little as $500 and able to comfortably fit on a workbench.

3D printing is able to create complex geometries and is likely to generate employment in niche manufacturing industries

Clearly, 3D printing will play a role in the future of manufacturing. It is capable of producing products unachievable by any other means, including those that comprise mixtures of materials. For example, its ability to create complex geometries is being used by General Electric to print components for its next generation LEAP engine. As such, it is likely to generate employment in niche manufacturing industries. It will enable nimble just-in-time manufacturing that is able to respond quickly to new demand. These demands could be rapidly determined using big data analysis enabled by the IoT and an increasingly networked society. Crucially, 3D printing is well suited to personalisation: products will be increasingly tailored to a customer's preferences, both explicitly stated and inferred from their data.

This personalisation comes to the fore in medical and dental applications, allowing components tailored to detailed body measurements. The industry is beginning to adopt 3D printing for commercial purposes: in particular, 3D printing is core to the manufacturing process of both Phona, manufacturer of hearing aids, and Align, manufacturer of Invisalign dental braces. Personalisation is also the driver behind the nascent industry that is starting to use 3D printing for clothing, such as Electroloom, who print using composites of synthetic and organic materials. For example, Continuum offers 3D printed bikinis, in nylon, bespoke to the body shape and measurements submitted by a customer through their website.

There will be some employment replaced by 3D printing, however it is unlikely to be of the same magnitude as other technologies mentioned in this report

The employment impact of these technologies, however, is unlikely to be of the same magnitude as others mentioned in this report. In the United States, for example, manufacturing has already been heavily automated, dropping from 30% of employment in 1950 to less than 6% today. The jobs that remain often involve a portfolio of skills, the management of many machines, for which one additional machine is unlikely to be able to substitute. Nor does the broad distribution of manufacturing devices, capable of personalisation, suggest a transformational change in employment. Similar developments were realised with the introduction of the home (2D) printer and sewing machine, which did not stop people from purchasing newspapers and clothes, respectively, from traditional suppliers.

The most significant influence of 3D printing, however, may also be the hardest to quantify. By lowering the barrier to manufacturing physical products, 3D printing may foster a new wave of innovation and the birth of new hardware startups, just as the lowering of the cost of producing software led to innovation and the birth of new software startups.

Automating the Design Process

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US IT Hardware & Software Analyst

From the beginning, the benefits of 3D printing were apparent in the industrial design process. 3D printing enabled "rapid prototyping" by speeding up the iterative design process. The technology allowed designers to iterate on designs in real time without the constraints of waiting for traditional job shop works to mill, mould or carve out physical prototypes. We are beginning to see the next phase with software vendors like Autodesk getting more involved in additive manufacturing (producing its own 3D printer). By more tightly integrating the hardware with software, we are beginning to see the next stage of additive design. Autodesk has applied computer learning into its CAD software, enabling engineers to simply determine *what* a product should do, leaving PCs and 3D printers to best determine the *hows* of design physics and assembly.

Automation Benefits of 3D Printing could "Bring Production Home"

Human involvement in the manufacturing process has decreased with additive manufacturing

Additive manufacturing also has the ability to drastically reduce the human involvement in the manufacture and assembly of end goods. Once a CAD design file has been converted into a 3D printer compatible STL file, the build process could theoretically be completely automated. 3D printing allows for complete freedom of design, enabling shapes previously unbuildable, including moving components within parts. The ability to print moving parts within a single build could potentially eliminate the need for factory workers to assemble the finished product. At this time, 3D printing is not completely absent human involvement; technicians are still needed to periodically monitor the fabrication process, empty build boxes, replenish consumables and perform some post processing (remove excess build material and in some instances polish items). However, even these basic manual processes are likely to be eliminated as printer OEMs are already trying to incorporate monitoring and continuous printing capabilities into systems (Makerbots now equipped with cameras, voxeljet has a built-in conveyor belt).

Indirect Impact on Logistics

As 3D printing lowers manufacturing costs, it may also lead to the revival of local manufacturing

As the total cost of ownership continues to fall, the eventual result could be the revival of local manufacturing. Bringing production closer to the end buyer does not specifically automate any distribution channels but we do see it streamlining many human elements needed to import goods from abroad (shipping, train trucking). As the ease of use continues to improve, an optimistic future could see 3D printers proliferate within the home. Some believe that manufacturers could one day simply sell consumers rights to design files similar to the iTunes model and put production of most consumer goods within reach of their fingertips.

We are still in the early stages of truly understanding the impact of 3D printing on the world of manufacturing. The heightened investments in this sector have enabled industry leaders to push the boundaries of the technology to new levels. Researchers are already exploring concepts such as virtual surgical procedures, self-healing parts, self-assembly (4D printing) and even self-creation. The common denominator with each new application is the ability for machine to extricate the human element from the process.

4. The World of Work in the 21st Century

What will the future of employment look like? Most past attempts to predict this have arguably been unsuccessful. In his famous chapter on machinery, published in the third edition of *The Principles of Political Economy and Taxation in 1821*, David Ricardo argued that the substitution of workers by machines may "render the population redundant."[75] In a similar vein, John Maynard Keynes predicted widespread technological unemployment as a result of mankind failing to find sufficient new uses for its labour as machines replace workers in old occupations and industries.[76]

The obvious reason why this concern has not materialised is that the replacement of workers by machines will have effects on all product and factor markets. An increase in the efficiency of production which reduces the price of one product will in turn increase real income and thus increase demand for other goods.

Technology has two effects on employment — the destruction effect and the capitalisation effect

In short, technological progress has two competing effects on employment. As it substitutes for labour, there is a destruction effect, requiring workers to reallocate their labour, but there is also the capitalisation effect, as the demand for other goods and services increase, and new occupations and industries are created.

Although the idea of technological unemployment did not materialise during the 20th century, there is growing concern that Keynes' prediction may come true. What will happen in the 21st century remains to be seen, but it is clear that the potential scope of job automation is expanding and will inevitably continue to expand. Meanwhile, the jobs created by digital technologies have so far largely been confined to skilled workers. In this section, we highlight these developments and their potential implications.

The Expanding Scope of Automation

Historically, automation has been confined to routine tasks involving explicit rule-based activities that can easily be specified in computer code.[77] The term "computer", for example, initially referred to an occupation stemming from the invention of calculus in the 18th century. With the advent of the electronic computer, the routine task of performing mathematical operations was transferred to machines, displacing human labour in the process.[78]

The scope of automation is increasing as algorithms for big data are able to perform a much broader scope of non-routine tasks

Since then the potential scope of computerisation has increased dramatically, and will inevitably continue to do so. Algorithms for big data are now rapidly entering domains reliant upon pattern recognition and can readily substitute for labour in a wide range of non-routine cognitive tasks.[79] Moreover, intelligent robots with enhanced senses and dexterity are now able to perform a much broader scope of non-routine manual tasks.

This is changing the nature of work across occupations, industries and countries. With the improved sensing available to robots, jobs in transportation and logistics are now at risk of automation. Take the recent development in autonomous vehicles, for example, potentially making bus, truck and taxi drivers redundant.

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75 Ricardo (1821).
76 Keynes (1930).
77 Autor et al. (2003).
78 Grier (2013).
79 Frey and Osborne (2013).

Although history tells us that one should be careful when making predictions about technological progress, we have a reasonably good idea about the type of tasks computers will be able to perform in the near future — not least since these technologies are already being developed, as described in Chapter 3, but are yet to be adopted on a larger scale.

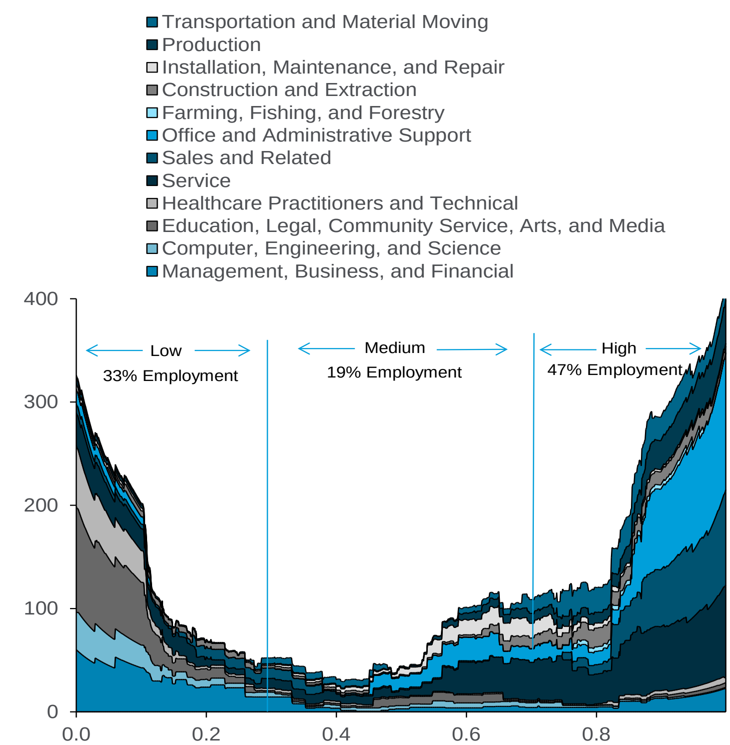
Occupations at Risk

47% of the US workforce is at risk of automation as a result of recent trends in technology

How significant will these developments be in terms of their employment impact? As shown in Figure 45, research by Carl Benedikt Frey and Michael Osborne, estimates that 47% of the US workforce is at risk of automation as a result of these trends.[80] Although this number cannot be directly transferred to other countries, the occupations that are at risk will be the same across countries and regions, including a wide range of jobs in transportation, logistics, and office and administrative support.

These findings speak to several trends we are currently witnessing in technology. Computerised cars are already being developed and augmenting vehicles with advanced sensors is becoming more cost-effective, making many jobs in transportation vulnerable. Algorithms for big data are also already taking over jobs that are reliant upon storing or processing information, suggesting that a growing share of office and administrative support jobs will soon be subject to automation.

Figure 45. Distribution of BLS 2010 occupational employment over the probability of computerisation



Source: Frey & Osborne (2013)

[80] Frey and Osborne (2013).

The bulk of service occupations in the US, where most US job growth has occurred in the past decades, are now at risk

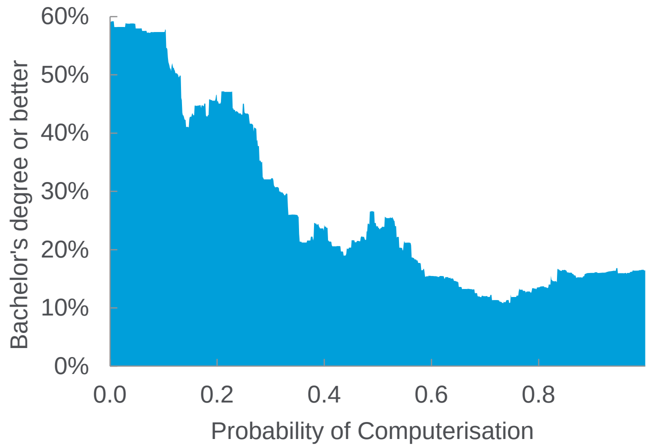
More surprising perhaps, is the finding that the bulk of service occupations, where the most US job growth has occurred over the past decades, are now at risk. Already the market for personal and household service robots is growing by about 20% annually — a trend that is likely to continue.[81] As machines get better at performing tasks involving mobility and dexterity, the pace of displacement in service occupations is likely to increase even further.

Although there is a growing popular perception that computers now mainly substitute for cognitive work, the victory of IBM's Deep Blue computer over chess grandmaster Garry Kasparov, or Watson's ability to outperform humans at US game show Jeopardy!, does not mean that most skilled jobs are now at risk. On the contrary, skilled jobs are relatively safe.

Low-skill and low-income jobs are for the first time at risk of being automated

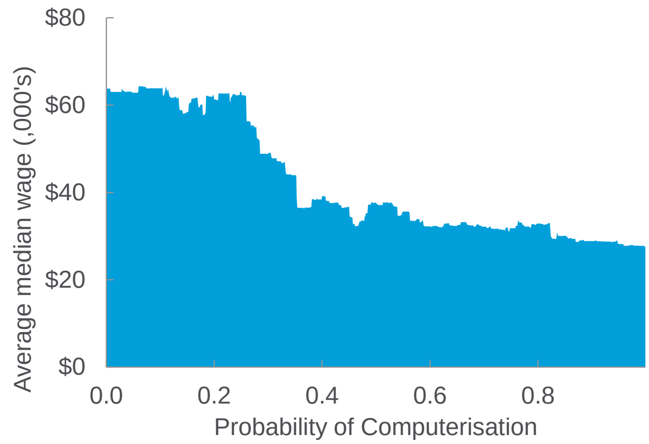
Instead, as shown in Figure 46 and Figure 47, low-skill and low-income jobs are now for the first time most likely to be automated. This implies a break from the trends we have seen in the past. While 19th century manufacturing technologies largely substituted for skilled labour through the simplification of tasks, the computer revolution of the 20th century caused a hollowing-out of middle-income jobs. Our estimates thus predict a shift from the computerisation of middle-income jobs, to computers mainly substituting for low-income, low-skill workers over the next decades.

Figure 46. Relationship between occupations at risk and education



Source: Frey & Osborne (2013)

Figure 47. Relationship between occupations at risk and wages



Source: Frey & Osborne (2013)

The common denominator for low-risk jobs is that they are intensive in social and creative skills. In particular, generalist occupations requiring knowledge of human heuristics, and jobs involving the development of novel ideas and artifacts, are not yet readily automatable. The reason is simple: computers do not yet have the human ability to engage in complex interactions, such as negotiating and persuading, and while they can now solve most crisp problems, they are not as good at developing original ideas.

As a result, most management, business, and finance occupations, which are intensive in work requiring social skills, but also most jobs in education and healthcare, are not fully automatable. The same is true of occupations that involve developing original ideas, such as many jobs in arts, media, engineering and science.

[81] MGI (2013)

Industries at Risk

Intelligent robots are now transforming industries such as construction, healthcare, professional services and finance

The expanding scope of automation promises future gains in productivity in a wide range of industries. In the same way the mechanised assembly line transformed manufacturing, allowing companies to substantially cut production costs, sophisticated algorithms and robots with enhanced dexterity are now transforming industries such as construction, healthcare, professional services and finance.

To estimate the industry employment impact the expanding scope of automation may have, we matched our occupation level data to the North American Industry Classification System (NAICS).[82] The susceptibility of various industries to automation thus reflects the intensity of different occupations and their probability of automation. For example, while all Tax Examiners work in the Government industry, only 44% of Computer Programmers work in Professional, Scientific and Technical Services. In fact, most occupations span across a wide range of industries.

Figure 48. Employment share at risk by industry

	Low Risk (%)	Medium Risk (%)	High Risk (%)
Accommodation & Food Services	2.8%	10.5%	86.7%
Administrative & Support Services	1.6%	36.2%	62.2%
Agriculture, Forestry, Fishing & Hunting	75.6%	12.0%	12.3%
Arts, Entertainment & Recreation	47.9%	12.5%	39.6%
Construction	21.6%	19.8%	58.6%
Educational Services	63.1%	19.7%	17.2%
Finance & Insurance	28.9%	17.3%	53.7%
Government	46.2%	30.6%	23.2%
Health Care & Social Assistance	39.4%	25.0%	35.6%
Information	51.6%	38.3%	10.1%
Management of Companies & Enterprises	82.8%	6.2%	11.0%
Manufacturing	19.9%	18.4%	61.7%
Mining, Quarrying and Oil & Gas Extraction	7.8%	46.3%	45.9%
Other Services (ex Public Admin)	44.9%	24.7%	30.4%
Professional, Scientific & Technical Services	54.0%	10.9%	35.1%
Real Estate and Rental & Leasing	0.7%	32.0%	67.2%
Retail Trade	14.5%	18.9%	66.6%
Self-Employed	60.4%	8.9%	30.7%
Transportation & Warehousing	5.5%	19.4%	75.0%
Utilities	40.3%	27.8%	31.9%
Wholesale Trade	15.9%	18.4%	65.7%

Source: Oxford Martin School

The susceptibility of computerisation varies substantially across industries

As shown in Figure 48, the susceptibility to computerisation varies substantially across industries. In Accommodation & Food Services, as many as 87% of workers are at risk of automation, while only 10% of workers in Information are at risk. Although several occupations in Information, such as Motion Picture Projectionists and Broadcast Technicians are highly susceptible to computerisation, these only constitute a fraction of the industry's total employment: 8,000 and 27,000 jobs,

[82] This analysis considered total employment of 98 million workers, against the 138 million considered in Frey and Osborne (2013). Available data from O*NET records employment in an industry if at least 10% of employment in an occupation is engaged in that industry, leaving some employment uncounted. For example, the breakdown for Electrical Engineers records that 38% work in Manufacturing, 31% work in Professional, Scientific and Technical Services and 10% work in Utilities, such that 21% of employment for Electrical Engineers is distributed amongst the other industries in an unspecified way. We assume that this unspecified distribution is not reflective of computerisability and that it does not introduce any systemic risk.

respectively.[83] By contrast, occupations such as Computer Network Specialists and Web Developers, of which many work in Information, already employ 143,000 and 141,000 workers, respectively, and are expected to add another 94,200 jobs before 2022, according to the US Bureau of Labor Statistics (BLS) occupational projections. This illustrates an important challenge facing companies in most industries: as low-skill jobs are being replaced and new high-skill jobs created, they will need to invest substantially in up-skilling their workforce.

Other industries that are at low-risk of automation include Management of Companies and Enterprise, and somewhat surprisingly Agriculture, Forestry, Fishing and Hunting, most likely reflecting that most jobs that can be automated in agriculture already have been. The potential scope for further automation is substantially larger in Manufacturing, where 62% of jobs are still at risk.

No single industry is completely immune to the expanding scope of automation

No single industry is completely immune to the expanding scope of automation. Even in some relatively skilled industries such as Finance and Insurance, 54% of jobs are at risk. Traditional low productivity industries such as Healthcare, Education and Government are facing future transformations too. At a time when government budgets are under pressure, such productivity gains would be a blessing.

Countries at Risk

Outside of the US, studies have found that upwards of 54% of EU jobs are at risk

To be sure, some countries are better positioned to adapt to the expanding scope of automation than others. Because different occupational classifications exist across countries, however, meaningful direct comparisons are notoriously difficult to make. In a recent study, for example, Bruegel translated our findings for the US to 28 European Union (EU) countries, using 22 (instead of 702) more aggregated International Standard Classification of Occupations (ISCO) job categories for which the International Labor Organization (ILO) provides consistent data. Doing so, they find that 54% of EU jobs are at risk of automation, spanning 47% in Sweden and 62% in Romania (see Figure 49).

However, these estimates are likely to be systemically upward-biased

Nevertheless, while the ILO data used by Bruegel is comparable across the countries they examine, the relatively crude occupational classification being used is likely to be systematically upward biased. Because many occupations with very different probabilities of automation often fall into the same broader category, and the employment share in occupations that have a higher probability of automation is likely to be relatively low, the Bruegel study most likely overstates the share of jobs at risk relative to the US. This is also suggested by other studies using more detailed occupational classifications for single European countries. According to a study by The Research Institute of the Finnish Economy (ETLA), examining 410 detailed occupations, about 37% of jobs in Finland are at risk of automation. Similarly, when translating our findings to the United Kingdom, analysing 369 occupations, we found that 35% of UK jobs are highly susceptible to automation, and in skilled places like London that figure is even lower (29.5%).

[83] Based on BLS employment figures for 2012.

Figure 49. Employment share at risk by country

Country	Frey & Osborne (2013) 702 occupations	Bruegel (2014) 22 occupations	ETLA (2014) 410 occupations	Frey & Osborne; Deloitte (2014) 369 occupations	SSF (2014) 109 occupations	Unionen (2014) 353 occupations
Austria		54%				
Belgium		50%				
Bulgaria		57%				
Croatia		58%				
Czech Republic		54%				
Denmark		50%				
Estonia		54%				
Finland		51%	36%			
France		50%				
Germany		51%				
Greece		56%				
Hungary		55%				
Ireland		49%				
Italy		56%				
Latvia		51%				
Lithuania		52%				
Luxembourg		50%				
Malta		51%				
Netherlands		49%				
Poland		56%				
Portugal		59%				
Romania		62%				
Slovenia		53%				
Slovakia		55%				
Spain		55%				
Sweden		47%			53%	37%
United Kingdom		47%		35%		
United States	47%					

Source: The Oxford Martin School

While there are a number of measurement problems associated with comparing countries according to their susceptibility to automation, it is clear that differences across countries and regions exist. The Bruegel study, for example, finds a strong negative relationship between a country's GDP per capita and the share of their workforce at risk of automation, suggesting that countries transition into jobs that are less susceptible to automation along the development path. In particular, developing countries are likely to find a larger share of their jobs at risk, as lower wages keep many jobs that are possible to automate from being displaced. However, as incomes rise and technological progress makes labour substitution cheaper, even these countries will eventually have to adapt. The challenge ahead for any country is managing this transition at a sufficient pace for workers to find new employment opportunities as existing jobs are being automated.

Technology and New Work

Entirely new occupations and industries are being created as a result of digital technology

Digital technologies do not only destroy jobs, but also create jobs in entirely new occupations and industries. For example, computer technology has recently given rise to many new occupations, such as database administrators and web designers. Beyond computer-related jobs, occupations such as that of the radiation therapist similarly underwent significant changes, following the arrival of new technologies. After the first magnetic resonance imaging (MRI) machine was patented in 1974, leading the way for the proliferation of MRI scanning techniques, a new occupational title emerged: MRI special procedures technologist, operating and monitoring diagnostic imaging equipment. Indeed, the more than 1,500 new job titles that appeared in the occupational classifications following the invention of the PC reflect a pervasive transformation of the world of work.[84]

New technologies have also created entirely new industries. Consider the Video and Audio Streaming industry, which appeared as a new title in 2010, following a series of recent innovations — in 1999, Apple developed QuickTime, a programme capable of handling various video formats, and in 2002, Adobe introduced Flash, a streaming format that is used by YouTube.

The Video and Audio Streaming industry is not an isolated example: Internet news publishers, Social Networking Services and Internet video broadcast sites are all new industry titles that are associated with the advent of the World Wide Web.[85]

Figure 50. New industries emerging from digitisation

Detailed Industry	% of New Industry Titles	% of U.S. Employment	% with College degree	Avg. Wage ($)
Internet publishing and broadcasting and web search portals	85.7%	0.06%	69.6%	$ 81,138
Electronic shopping	42.8%	0.08%	49.7%	$ 45,372
Data processing, hosting, and related services	32.0%	0.08%	48.0%	$ 64,729
Electronic auctions	66.6%	0.01%	52.2%	$ 47,257

Source: Berger and Frey (2014b)

However, studies have found that the number of new jobs created from the arrival of new technologies throughout the 2000s has been strikingly small

Although there are a number of measurement problems associated with examining the share of jobs that stems directly from new technologies, new industry titles that emerge in official classifications as a result of new technologies becoming available, at least provide an indication. Thus, a recent study by Thor Berger and Carl Benedikt Frey used such data to systematically capture employment opportunities created by new industries of the 2000s in the United States. Their findings are quite revealing. First, the magnitude of new jobs created from the arrival of new technologies throughout the 2000s has been strikingly small: in 2010 only about 0.5% of the US workforce was employed in new industries that did not exist a decade earlier.[86]

Second, workers in these industries are substantially better educated than the average population and earned much higher wages: the average wage for workers in new industries is more than twice the US median wage. For any given level of education, workers with a STEM degree are also more likely to work in new industries.

Jobs created through technological progress have been largely confined to skilled workers

Hence, in short, although technological progress continues to create new jobs, these have largely been confined to skilled workers. Cities and nations with a large pool of skilled workers have thus benefited disproportionally from recent technological change.

[84] Berger and Frey (2014a).
[85] Berger and Frey (2014b).
[86] ibid

The Concentration of New Work and the Rise of Innovation Cities

While it is clear that the arrival of digital technologies have created new employment opportunities, new work has become relatively concentrated over time. As a result, most people who have not followed the new jobs have not directly seen the benefits of their emergence.

New work tends to concentrate in skilled cities as industries become more knowledge-intensive

The concentration of new work largely stems from the shift towards tech industries and finance, where knowledge transmission is particularly important. The continuous renewal of prominent clusters like Silicon Valley is largely the result of workers frequently switching jobs, leading to the creation of new companies and industries.

For example, about a year after Shockley Semiconductor Laboratory was founded in 1956, several of its engineers left and created a new company: Fairchild Semiconductor. Two of these would go on to form Intel in 1968. In the same way, frequent job-hopping and the pool of skilled workers has recently attracted a new generation of companies leading the digital revolution: Google, Facebook, eBay and LinkedIn, are all based in Silicon Valley. Similarly, Instagram, Dropbox, Uber, Internet Archive and Twitter are all located or began in San Francisco.

The concentration of new work has led to divergence across cities and regions

The consequences of the concentration of new jobs and industries are particularly evident in America, where cities have fared very differently over recent decades. In his recent book *The New Geography of Jobs*, Enrico Moretti nicely illustrates the divergence across US cities, using the example of Visalia and Menlo Park — two cities that are about a three hour drive apart. Although the cities were not identical, they had similar crime rates and schools of comparable quality as recently as the 1960s.[87] Workers in Menlo Park were on average slightly better educated and earned somewhat higher wages. Today, the two cities are worlds apart. While Visalia has the second lowest percentage of college educated workers in America, half of Menlo Park's residents have a college degree, and the city still keeps attracting new tech companies, including Facebook.

In *The World Is Flat*, Thomas Friedman famously argued that the digital age would make location irrelevant.[88] Yet so far the opposite has been true. The digital age has in fact been a chief driver of the Great Divergence between cities. According to a recent paper by Thor Berger and Carl Benedikt Frey, cities with larger pools of skilled workers before the advent of the Computer Revolution of the 1980s have been in a much better position to take advantage of new technologies, leading to a substantially faster shifting of workers into new occupations.[89]

Older manufacturing cities are being taken over by new economic powerhouse cities

Meanwhile, old manufacturing cities such as Buffalo, Cleveland or Detroit have become increasingly associated with urban obsolescence as new economic powerhouses are replacing old ones. The growth of cities like Shenzhen, where the iPhone is assembled, almost perfectly mirrors the decline of US manufacturing locations. In short, the restructuring of global supply chains, enabled by improvements in information technology, and the rise of skilled innovation cities, has changed the world of work significantly. While nations have been converging, cities in the rich world have been diverging.

[87] Moretti (2013).
[88] Friedman (2005).
[89] Berger and Frey (2014a).

For workers in the rich world, the digital age has thus been a mixed blessing. Although people living in skilled cities have benefited, many workers in old manufacturing cities have not. Furthermore, as skilled cities are becoming more attractive, rising house prices makes them less affordable places to live. This has implications particularly for the poor, who often cannot afford to relocate to places where new jobs are available — something that is evident from studies of both America and France.[90]

Housing constraints can also provide constraints on growth. A recent study estimates that between 1964 and 2009 output in America was 13% below its potential, due to constraints to housing supply in skilled cities.[91] Thus, so far, the digital economy has made geography more important, not less.

Self-Employment: The New Normal?

Yet in theory, the digital economy could make geography less important, and in some cases it has. For example, a recent story in the *Financial Times* featured a self-employed worker based in Dharavi — a slum in Mumbai — making around $20,000 annually selling goods through eBay.

In some cases the digital economy can make geography less important as entrepreneurs can offer goods to a global market

An important feature of the digital economy is that it allows even people in deprived areas to reach global markets, as even more traditional goods have become increasingly mobile. Etsy provides such an example, allowing local artisans to reach customers all over the world through its online platform. In addition to around 750 workers employed in the company's Brooklyn office, some 1 million self-employed artisan sellers have emerged worldwide.[92] These entrepreneurs all take advantage of the opportunities provided by the digital economy, offering their crafts to the global market.

At the same time, e-entrepreneurship typically requires less capital investment, while online platforms for crowdfunding make capital more accessible. In other words, digital technologies have made self-employment an option to a growing share of workers. This is reflected by the emergence of the "app economy", which has grown substantially since Apple launched its app store in 2008. According to a recent estimate the app economy today provides work for more than 750,000 Americans.[93] [94]

Yet, while self-employment has been on the rise since the turn of the century, its causes remain unclear. In Britain, the number of people in self-employment has increased by more than 30% since 2000, with the result that one in seven is self-employed.[95] In America, the rise of self-employment has been even more substantial, growing by nearly 50% over the same period.

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[90] Anderson et al. (2014); Gobillon, Selod and Zenou (2007).
[91] Moretti and Chang-Tai Hsieh (2014).
[92] The Economist (2014a).
[93] Progressive Policy Institute (2013).
[94] Citi's Internet analyst estimates the "App Economy" grew 45% in 2014 to reach $29 billion and could grow to $52.5 billion by 2017. Native apps, as opposed to web browsers, have become the primary means of consumption on mobile devices. Mobile apps make money from paid downloads, app marketing, app commerce and app advertising. Both Google and Apple share 70% of gross booking with app developers. While gaming apps and Facebook consume much of the time spent on apps today, productivity apps are growing quickly, suggesting a broadening of the use case for mobile phone apps.
[95] Dellot (2014).

Self-employment is on the rise since the turn of the century, but the reason for the rise is unclear

Disentangling the reasons behind the surge in self-employment is difficult due to the limitations of the data. For example, some people do not report income from self-employment, while others just do it on the side in addition to having a full-time job. Nevertheless, some evidence on the underlying drivers of self-employment exists.

To be sure, unemployment is a part of the story. A recent study found a close link between the unemployment rate in a given American locality and the rate of new business startups.[96] Similarly, according to a recent survey of Britain by the Royal Society of Arts and Populus, 27% of those who started up in the recessionary period of the last five years did so to escape unemployment. Yet, the largest increase in self-employment since 2008 has been in professional occupations, consisting mainly of relatively skilled workers.

The growing skills gap may thus be another reason, causing employers to rely increasingly on contractors. Indeed, as digital technology becomes more heavily integrated in the daily operations of firms across a wide range of industries, digital literacy will become crucial for the vast majority of workers. Yet, according to the European Commission, some 47% of European workers have insufficient digital skills; 23% have none at all.[97]

Self-employed workers are happier with their working lives

At the same time, self-employment is becoming more socially acceptable and thus increasingly a preference. In Britain, 84% reported that self-employment made them more content with their work. In another survey by the Resolution Foundation, 73% of respondents said their move into self-employment partially or largely reflected personal preference, although a growing minority indicated they had gone self-employed because of a lack of alternative options.[98]

The idea that workers should expect to stay with the same employer until retirement seems somewhat dated. While the recent surge in self-employment is clearly associated with unemployment, this is only one side of the story. The digital economy is making self-employment more attractive for skilled entrepreneurs, but also provides opportunities for less skilled workers in deprived areas: Freelancer.com and Elance-oDesk already connect 3.7 million businesses with 9.3 million workers. As the economy is becoming increasingly digitised, self-employment may even become the new normal.

[96] Fairlie (2013)
[97] European Commission (2013).
[98] Resolution Foundation (2014).

5. Digital Transformation: Risks and Opportunities

Like every technological revolution, the digital transformation entails risks and opportunities. By understanding the associated challenges, the risks can be mitigated, and by taking advantage of the opportunities, the benefits of digitisation can be maximised. This chapter seeks to shed some light on the digital transformation ahead in terms of related risks and opportunities.

Risks

Inequality

The rise in inequality in the world is indisputable and can be partly explained by skill-biased technological change

The rise of inequality in the rich world is indisputable—both in terms of wealth and income. Oxfam in a recent report calculated that the richest 85 people on the planet in 2014 owned as much as the poorest half of humanity. While much has been written about the top 1%, the surge in income inequality among the other 99% is equally striking. Much of this rise can be explained by what economists refer to as skill-biased technology change, increasing the demand for educated workers.

In America, the college premium began rising in the late 1970s — between 1980 and 2005 about two thirds of the rise in earnings dispersion can be accounted for by the premium afforded to education. Cognitive skills, especially, are today rewarded across the labour markets of all 22 OECD economies, although there is substantial dispersion. In countries like Sweden, Norway and the Czech Republic, the premium is below 13%, while countries like the United Kingdom, Ireland, Germany and Spain, exhibit premiums above 20%. [99]

At the same time, the proliferation of digital technologies has reduced the demand for workers in a wide range of manufacturing and clerking tasks. The result: a secular decline in employment in traditional middle-income jobs, accompanied by a structural shift in the labour market, with workers reallocating to low-income jobs that are less susceptible to automation, further worsening income inequality.[100]

The top 1% income share has more than doubled over the past three decades

In addition, over the past three decades, the top 1% income share has more than doubled. A possible explanation for this is described by Sherwin Rosen in a 1981 paper entitled *The Economics of Superstars*, arguing that technological changes allowing the best performers in a given field to serve a bigger market would lead to a 'winner-take-all' effect.[101] This feature of the digital economy, allowing companies such as Google, Facebook, Instagram and WhatsApp to capture almost their entire market, would explain the growth of the share of income accruing to the top 1%.

Yet, while other Anglo-Saxon countries have witnessed similarly sharp increases in the top 1% income share, there is substantial variation across countries: many other advanced countries such as Japan, Germany and France have seen much more modest increases in the top 1% income share.[102] Thus, it seems that common factors such as technological change and globalisation cannot account solely for this phenomenon. The regulation of markets, tax policy, remuneration systems, and approaches to corporate governance that prohibits rent-seeking, all play a role.

[99] Autor (2014)
[100] Autor and Dorn (2013); Goos et al. (2007).
[101] Rosen (1981).
[102] Alvaredo et al. (2013).

Because digital technologies can substitute labour for capital, productivity improves while wages do not

Furthermore, digital technologies make it easier to substitute labour for capital. Although such substitution helps productivity, it does not boost wages. Instead it merely enhances the capital share of income, leading to a higher concentration of wealth. As a result, while income inequality is on the rise, the concentration of wealth is also striking. According to a recent study the wealthiest 0.01% of American families now control 11.2% of total wealth: about the same share as back in 1916, which is an all-time high.[103]

The relationship between wealth and income inequality across countries is however far from intuitive. In some countries like America, both are high, whereas places such as South Korea exhibit both low wealth and income inequality. Countries such as Switzerland and Denmark, on the other hand, have relatively low levels of income inequality, but also the highest levels of wealth inequality in the OECD.[104]

Perfect equality may not be desirable. Financial gain is important to spur risky entrepreneurship and innovation. This means, as Arthur Okun famously argued, that societies must make trade-offs between equality and efficiency. Nevertheless, extreme inequality can also lead to inefficiencies. Not least since income inequality tends to translate into inequality in wealth, health, and exposure to crime.

Economic inequality often results in political inequality, which is a concern

Furthermore, as highlighted in the recent book by Daron Acemoglu and James Robinson, *Why Nations Fail*, economic inequality often results in political inequality, where: “those with great wealth and easy access to politicians and policymakers will try to increase their power at the expense of society. That sort of hijacking of politics is a sure-fire way of undermining inclusive political institutions, and it is already under way in the US.” There are thus good reasons to be concerned by the rise of inequality.

Automation, Inequality and the Equity Market

Robert Buckland
Chief Global Equity Strategist

The booming stock market is part of the inequality story, but is it associated with automation? Automation is a key driver of productivity growth — the amount of output produced per worker. In turn, productivity is the key driver of long-term economic growth. Economic growth is the key driver of long-term corporate earnings per share (EPS). And finally, EPS growth is the key to long-term stock market returns. Equity investors have been clear beneficiaries of the economic gains associated with automation.

That’s the long-term story. But can we find evidence that accelerating automation is proving especially beneficial for shareholders right now? And are workers losing out as a result?

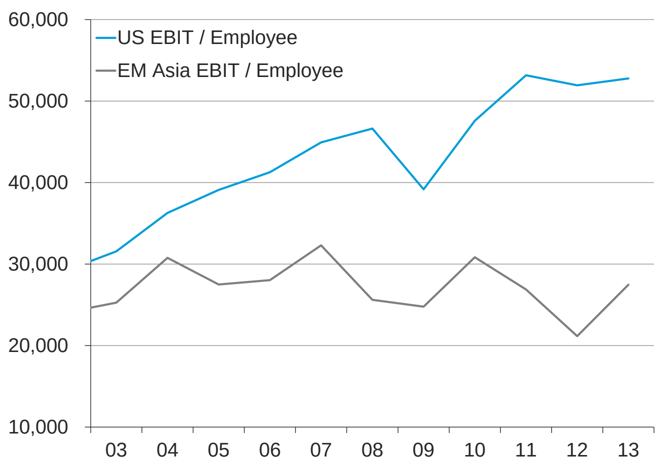
Whether technological innovation is driving capital substitution for labour is notoriously difficult to measure. One potential measure is the progression of profits relative to the number of company employees. We have aggregated both for the non-Financial listed US companies represented in the MSCI US benchmark.[105] We also show the same calculation for the MSCI EM Asia index, on which we comment more later.

[103] Saez and Zucman (2014).
[104] The Economist (2014b).
[105] This reflects the largest (often multinational) companies that dominate the US stock market. It closely tracks the S&P benchmark. Like the S&P, it omits the employment decisions of smaller unlisted companies which are important drivers of the US payroll data.

In the past 10 years, US-listed non-Financial companies have seen a 119% increase in EBIT but only a 31% increase in number of employees

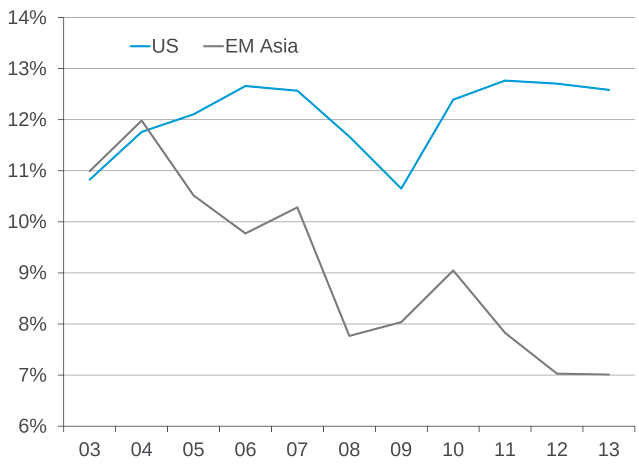
The dominant US-listed non-Financial companies generated EBIT (i.e. earnings before interest and tax) of $1.3 trillion in 2013, up from $600 billion made 10 years earlier. These same US blue chip companies employ 24 million workers, up from 18 million in 2003. That's a much bigger increase in EBIT (+119%) than number of employees (+31%). As a result, the 'profits productivity' of the US stock market has risen sharply. EBIT per employee is up from $32,000 in 2004 to $53,000 in 2013 (Figure 51).

Figure 51. Non-Financials EBIT/employee ($)



Source: Worldscope, Factset, Citi Research

Figure 52. Non-Financials EBIT margin



Source: Worldscope, Factset, Citi Research

Perhaps this reflects the impact of automation. US workers are being replaced by increasingly sophisticated machines. These machines don't take sick-leave. They don't ask for pay rises or take holidays. They don't go on strike or demand better working conditions. Even the tax system is tipped in favour of machines — capital expenditure (capex) is tax-deductible in most countries. Hiring more workers usually involves paying more payroll taxes.

Lower rates of unionisation in the US could be a reason for the deteriorating bargaining position of US workers while the shift of low-skilled manufacturing is another important driver

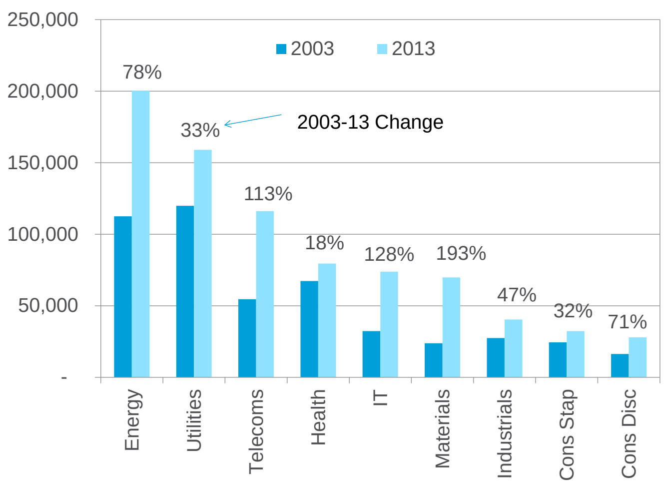
We can find plenty of evidence to suggest that the bargaining position of US workers has deteriorated in recent years. Listed non-Financials EBIT are up 119% since 2003, but hourly earnings in US manufacturing are up only 22%. Profit share of GDP is up, wages share of GDP is down. Academic studies have attributed some, but not all, of this to automation.[106] Lower rates of unionisation are also seen as a reason. Globalisation, especially the shift of low-skilled manufacturing jobs to Asia, is seen as another important driver. Overall, these factors seem to have been more helpful for shareholders than workers. Despite a lacklustre economic recovery since the financial crisis, US non-Financial profit margins are back around pre-crisis highs (Figure 52).

We can then break the US market down by sector. Figure 53 shows that in 2013, with the oil price above $100/bbl, the Energy sector generated the highest income per employee. This highly profitable, automated and capital intensive industry earned $200,000 per employee, up 78% since 2003. Of course the subsequent collapse in the oil price will now be putting intense pressures on sector profits. Other industries which have seen a sharp increase in profitability per employee, perhaps indicating intensifying levels of automation, include Telecoms, Information Technology and Materials.

[106] For a summary of the current debate around the labour share of GDP, please see Giovannoni (2014).

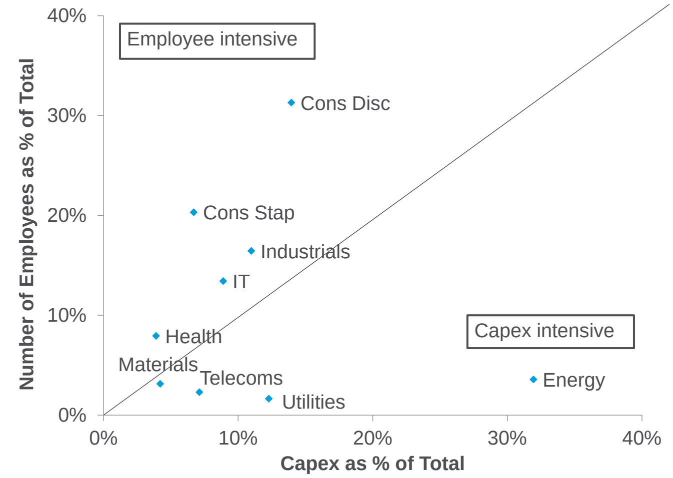
Towards the bottom of the profitability/employee ranking are the two Consumer sectors, although it is interesting to see that Consumer Discretionary (which includes Retail stocks) have seen a sharp rise in employee profitability (+71%) in the past 10 years. This may indicate a rising level of automation in a traditionally employee-heavy sector.

Figure 53. US listed non-Financials: EBIT per employee (%)



Source: Citi Research, Factset, Worldscope

Figure 54. US listed non-Financials : Employees vs. Capex



Source: Citi Research, Factset, Worldscope

While we can identify shifts in employee profitability, the very different nature of each industry will be reflected in very different levels of capital or employee intensity. Figure 54 shows that the Energy sector accounts for 32% of total capital spending by US non-Financials. But it only employs 12% of workers. Of course, the booming oil prices (until last year at least) will have boosted jobs in the US Energy sector, but it has boosted capex by much more.

By contrast, Consumer Discretionary employs 31% of workers but spends only 14% of total capex. If the capex/employee relationship is some indicator of current levels of automation, we might expect the US Consumer Discretionary sector to offer more opportunities to replace workers with machines then Energy.

Emerging Asia is Different

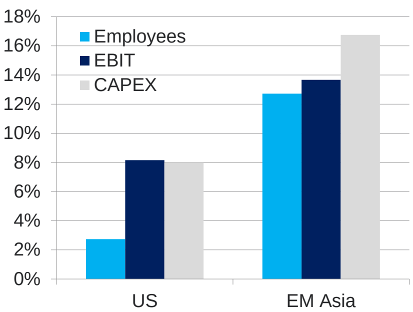
So that's the US story. Shareholders of listed companies have benefited more than their workers, as indicated by a sharp rise in profitability per employee. Some of this is attributable to higher levels of automation. But what about other parts of the world? Can we also see a shift towards shareholders and away from workers, partly driven by automation? To examine this, we look at similar data for listed companies in Asia as reflected by the MSCI EM Asia index. [107]

The key listed non-Financial companies in emerging market (EM) Asia generate EBIT (i.e. profits before interest and tax) of $340 billion, up 260% from the $94 billion made 10 years ago. This is around 2 times the growth than their US counterparts, partly reflecting much stronger Asian economies over the period. However, unlike the US, EM Asia non-Financial have been hiring as fast as they've been growing profits. The total employee count of the MSCI EM Asia non-Financial companies is now 12 million (a remarkably low number in a continent of 4 billion

[107] This index is dominated by China (32%), Korea (23%), Taiwan (19%) and India (11%).

people) compared to just 4 million in 2003. As a consequence, EM Asia net income per employee has been flat in the past 10 years (Figure 55). It is harder to argue that there has been an automation-driven shift that has helped shareholders relative to workers. Unlike the US, EM Asia profit margins have fallen over the period (Figure 52).

Figure 55. Growth per year



Source: Citi Research, Factset, Worldscope

To summarise all these differences, Figure 55 compares the growth in employees, EBIT, and capex for US and EM Asia non-Financial companies. In the US, employee growth has lagged well behind EBIT and capex growth, perhaps suggesting accelerating automation. But for EM Asia companies, the divergence between capex and employment growth has been less intense (Figure 55). Capex has been more of a complement than substitute for labour.

The Market Cares about Returns

Investors are becoming increasingly obsessed (again) with technology stocks. This has distorted the relationship between market valuations and company employees. For example, internet company WhatsApp, with just 55 employees, was recently bought by Facebook for $19 billion. This is a similar valuation to retailer Gap which has 137,000 employees. WhatsApp is priced at $345 million/employee compared to Gap at $124,000/employee. We suspect this reflects a potential bubble in selected IT stocks rather than an explicit investor desire to buy more automated companies. Indeed, across the broader market, there is little evidence to suggest that investors value capex-heavy/automated companies much more highly than their more employee-driven peers. For example, we have already seen that the US Energy sector was responsible for 32% of total market capex in 2013. But it currently accounts for only 12% of equity market valuation. New capex, and associated technological innovation, can be disruptive for incumbents and highly profitable for the innovators. But it can also end up being highly deflationary for the industry as a whole. Shale oil is an obvious current example of this theme.

Stock markets care about investor returns — whether these are maximised by robots or people is less of a concern

In the end, stock markets care most about investor returns. Whether these are maximised by using robots or people is less of a concern. For US-listed companies a sharp profit recovery in recent years has been associated with strong capex but sluggish employment growth. For EM Asia companies, strong profit growth has been associated with strong capex *and* strong employment growth. Even if the employment profiles look quite different, shareholders have benefited from higher profits in both the US and EM Asia, but those profits have been achieved in different ways.

As labour costs start to catch up with those in the US, perhaps Asian companies will increasingly turn to automation in order to keep costs down and profits up. A US-style gap between profit growth and job creation could start to open up. This may keep shareholders happy but could also be associated with stagnating labour markets and subsequent social and political tensions. It may also bring a slow-down in end demand growth. After all, machines may make model employees, but they do not make particularly enthusiastic customers.

Macroeconomic Stability Risk

The surge in income inequality has been accompanied by a sizeable increase in borrowing, which has helped sustain consumption levels

While real pay for most ordinary workers in the rich world has stagnated or even fallen, economists have long understood that it is not income that matters but consumption. Importantly, in America, the hollowing-out of middle-income jobs and the surge in income inequality has been accompanied by sizeable increases in borrowing, which has helped sustain consumption levels.

In his book *Fault Lines: How Hidden Fractures Still Threaten the World Economy*, Raghuram Rajan argues that the credit expansion before the financial crisis of 2007 was the result of political pressures to maintain the consumption levels of the increasingly squeezed middle. Thus, the underlying cause of the financial crisis was the rise in inequality, encouraging the provision of easy credit to boost employment despite stagnating incomes.

A recent *IMF Working Paper* similarly shows that the period leading up to the crisis was characterised by high-income individuals saving more, and increased borrowing among low-income workers, leading to lower consumption inequality relative to income inequality.[108] The increase in saving and borrowing, in turn, created a growing demand for financial services, intermediating borrowers and lenders. The result can be seen in the ratio of banks' liabilities to GDP, which increased substantially. This build-up of household debt that culminated in the financial crisis of 2007 was no doubt more costly than redistribution policies to reduce the underlying problem: income inequality. From a macroeconomic stabilisation point of view, policies to reduce inequality and excessive credit expansion ex-ante would thus be preferable to ex post bailouts or debt restructurings.

Although the recent surge in inequality may not have been the sole cause of the financial crisis, it is a risk to macroeconomic stability

However, an empirical association between income inequality and credit booms does not necessarily imply causality: both inequality and credit expansion can occur as a result of a third factor. Financial market liberalisation, for example, may have increased the relative earnings of the financial sector, and has thus contributed to growing income inequalities. To be sure, the recent surge of inequality may not have been the sole cause of the financial crisis, but it is nevertheless a risk to macroeconomic stability.

Secular Stagnation

As sophisticated algorithms and computer-controlled devices are likely to replace mainly low-skilled workers, already growing income inequality is likely exacerbated. At the same time, the capital share of income may increase even further, benefiting those with a lower propensity to consume. The result: reduced spending in the economy and permanently lower aggregate demand.

Growing inequality could lead to a period of secular stagnation

As has been pointed out by Lawrence Summers, growing inequality could lead to a period of secular stagnation. Yet growing inequality is not the only force that may cause stagnation. The very nature of the digital economy itself could cause stagnant or even falling growth rates.

The secular stagnation thesis was presented by Alvin Hansen during the Great Depression. According to Hansen's theory, a slowdown in population growth and the rate of capital-absorbing innovation would cause net savings at full employment to grow, and net investment to fall. This, in turn, would result in a savings glut and slower growth caused by a decline in new investment opportunities.

[108] Kumhof and Ranciere (2010).

Over recent decades, the US economy has witnessed a downward trend in indicators of technological dynamism: the rate of business startups and the pace of job relocation have recently fallen, while the share of US employment accounted for by young firms has declined sharply throughout the 2000s.[109] Even the high-tech sector started to decline in the post-2000 period, experiencing a shift in economic activity away from young to more mature firms.

An appealing, but mostly neglected, explanation for this is offered by the life-cycle pattern of the computer revolution. As investment in computer and information processing equipment surged throughout the 1980s and 1990s, a wide range of entirely new computer-related jobs were created. Beyond the peak investment stage in 2000, however, the US economy experienced a decline in the demand for new work relative to the early stages of the computer revolution.[110] The question thus arises: where will the next generation of capital-absorbing innovations come from?

Stagnation, according to Hansen, stems from a slowdown in technological progress…

In Hansen's framework, stagnation stems from a slowdown in technological progress, resulting in fewer investment opportunities. Indeed, a number of economists, including Robert Gordon and Tyler Cowen, have suggested that the most useful innovations have already been made.[111] Yet the technological opportunities offered by the digital revolution may well be greater than anything we have seen in the past.

…but sluggish job creation in digital industries does not necessarily imply a slower or faster pace of innovation

Crucially, the sluggish job creation in digital industries does not necessarily imply a slower or faster pace of innovation. Instead, it stems from the fact that digital innovation is much less capital-absorbing, meaning that there is little demand for labour to build the new capital. While WhatsApp started with $250,000 of seed funding, they still only employed 55 workers at the time the company was acquired for $19 billion.

That the digital economy may cause secular stagnation is a real risk.[112] The simple reason is that businesses of the digital revolution require less capital investment and thus fewer workers to build the new capital, relative to the investment opportunities brought by technological revolutions of the past. As economies are becoming increasingly digitised, investment opportunities will continue tapering off. Accompanied with a rising share of profits, the savings glut is likely to persist.

Macro Policy Implications

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The risk of secular stagnation has significant implications for policy. The stance of monetary policy at any moment depends crucially on the output gap, or the difference between potential GDP, which assumes full utilisation of available inputs (land, labour and capital), and actual GDP, the amount of expenditure actually occurring in the economy. When potential GDP is running above actual, this means that slack and underutilisation is abundant, leading to downward pressure on wages and prices and thereby to action by the central bank to ease monetary policy to meet its inflation target. Conversely, actual GDP running above potential implies an overheating economy and a tightening stance of monetary policy.

[109] Decker et al. (2014).
[110] Frey (2015).
[111] Gordon (2012); Cowen (2011).
[112] Frey (2015).

Macro policy depends on whether actual GDP can keep up with potential GDP

Everything else being equal, skill-biased technological change would increase potential GDP by making both capital and labour more productive in the production process. The question then is whether actual GDP can keep up with potential, absent policy intervention.

There is some empirical evidence to suggest that if technological change occurs at the high end of the skill distribution, causing wage gains to be concentrated there, the answer is no. In that scenario, skill-biased technological change may lead to a persistent gap of potential GDP over actual GDP, leading to downward pressure on inflation and thereby to chronically depressed central bank policy rates.

Saving and investment decisions drive the gap between potential and actual GDP

The mechanism driving the growing gap between potential and actual GDP works through saving and investment decisions. If skill-biased technological change occurs at the upper end of the skill distribution, wage gains are likely to be concentrated where income levels are already relatively high. The academic literature, on balance, favours the idea that saving rates rise with income.[113] Hence, skill-biased technological change may result in more income flowing to those with relatively high saving rates, depressing aggregate consumption demand. Weak consumer spending may in turn negatively impact capex decisions at firms, which are a function of future consumer demand. The end result in this stylised example is that aggregate expenditure in the economy is unable to keep up with the economy's potential, leading to subdued wage and inflation pressure and thereby to a persistently loose stance of monetary policy.[114]

In addition, technological change could depress policy rates through a mechanism unrelated to the wage distribution, by resulting in a decline in the relative price of investment goods (think cheapening of personal computers). This process has already been underway for decades.[115] If new technology continues to make certain goods in the economy relatively cheap, that could result in downward pressure on overall price inflation, leading to a bias by central banks to favor lower policy rates.

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[113] For example, in Dynan, Skinner and Zeldes (2006), savings in the bottom income quintile are roughly zero compared to over 25% of income in the highest quintile. Consistent results hold for proxies of permanent income, such as levels of educational attainment and lagged and future earnings obtained from longitudinal surveys.

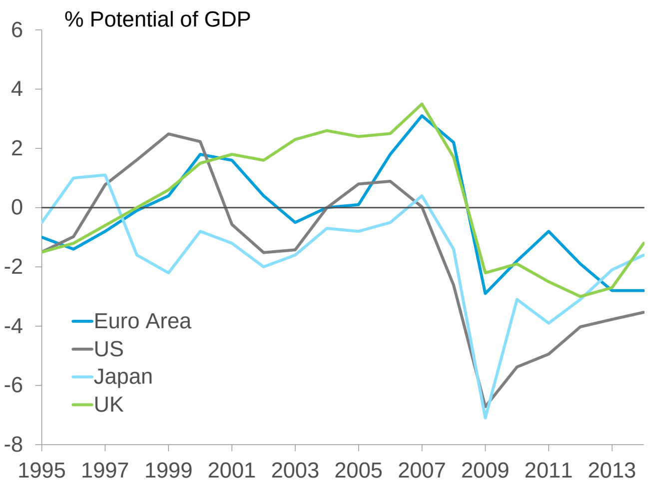
[114] As mentioned, all of this is 'everything else equal.' In an open economy setting, capex decisions are not made solely on the basis of expected future domestic consumer demand; rising foreign demand could offset the weakness in investment spending brought on by high domestic saving patterns. Moreover, demographics complicate the picture greatly. Older people tend to spend more than younger people. Thus, aging demographics, which are occurring in a number of advanced economies, will likely put upward pressure on domestic consumer spending, thus leading to an upward bias on policy rates – see Goodhart and Erfurth (2014). Finally, borrowing constraints matter greatly. Steve Randy Waldman argues that so long as debt accumulation by lower-wage earners occurs alongside growing wage inequality, it will negate the consumption-depressing effects of growing wage inequality – Waldman (2012). Moreover, Gauti Eggertsson and Neil Mehrotra describe an overlapping generations model where a within-generation rise in wage inequality leads to an excess of the supply of savings over the demand for savings, thereby depressing the real interest rate, provided that those demanding savings (those in the younger generation and those at the bottom of the wage distribution in the generation that saw an increase in wage inequality) are credit constrained – see Eggertsson and Mehrotra (2014).

[115] In Buiter, Rahbari and Seydl (2014), we document that since 1970, the average price of a unit of investment for a broad range of advanced economies has fallen by roughly 17% relative to the price of a unit of GDP and by 20% relative to a unit of personal consumption (as measured by the PCE deflator).

Large global output gaps are likely not a result of technological change

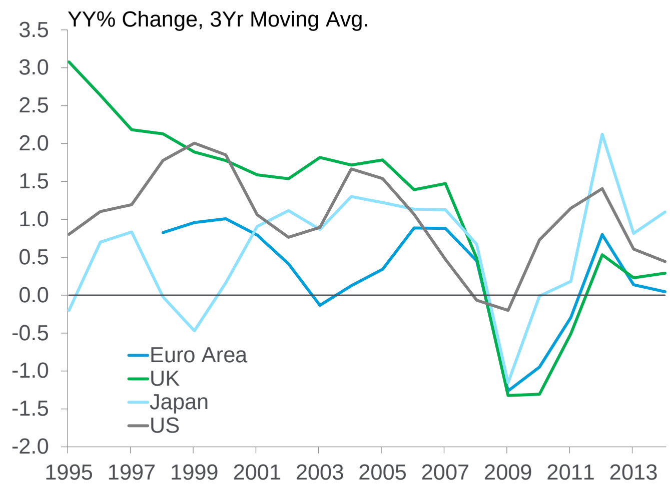
Empirically, it is true that much of the advanced world is still grappling with large output gaps following the fallout of the 2008 global financial crisis (Figure 56). Is that a result of technological change and the robotics revolution? Probably not. That outcome probably has more to do with the long-lasting demand-side effects of the previous business cycle. Many advanced economies remain in debt-deleveraging mode from years of excessive debt accumulation (especially in the housing sector), and this has held back consumer spending and business investment. In fact, for all the talk of a 'Second Machine Age,' it has yet to show up in the productivity data; total factor productivity, a measure of an economy's long-term technological dynamism, has not noticeably sped up on the back of the robotics revolution (Figure 57). In other words, the output gaps we are observing are not a result of accelerating potential GDP but of weakly growing actual GDP.[116]

Figure 56. Output gap



Source: IMF

Figure 57. Total factor productivity growth (3-year rolling average)



Source: European Commission

To be sure, tracking economy-wide productivity in real time is a difficult empirical endeavour; one in which economists don't have a good track record. And there may be good reasons to think that the official productivity data are not tracking changes in the information economy quickly enough.[117] So what do the data on wages say? Are they accelerating at both ends of the skill distribution in line with the job polarisation story, or just at the high end?

The answer depends on the country under consideration. The United States has seen wages accelerate at the high end of the skill distribution much more quickly than at the low end (Figure 58). The same is true for Canada, Germany and

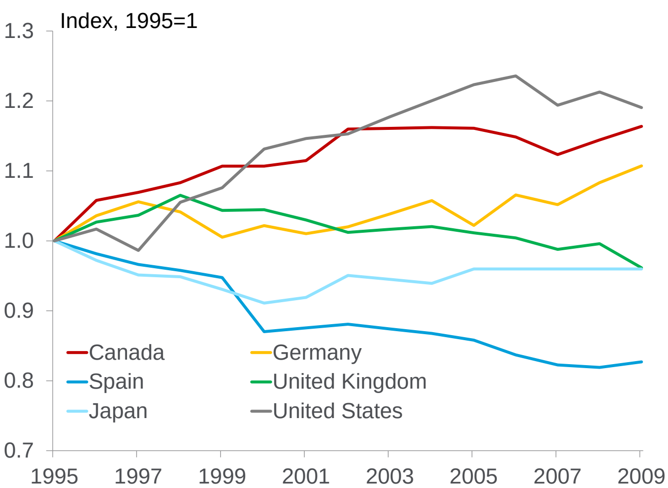
[116] If anything, the sluggish recovery since the global financial crisis has served to reduce the growth rate of potential GDP through 'hysteresis effects' (e.g., workers losing their skills from being out of the labour force for an extended period). See Summers (2014).

[117] One concern is that the statistics on economic output do a poor job of tracking goods and services that, while expensive to design initially, can be copied at very low or zero marginal cost. See Mokyr (2014). In addition, Barry Eichengreen emphasises the importance of "range of adaptation" with regard to new technology, meaning that it often takes time for existing industries to reorient themselves around new technological breakthroughs. While robotics is disrupting production in a number of industries, it may take a while for the effects to fully show up in the economy-wide productivity statistics. See Eichengreen (2015).

Australia. In contrast, the United Kingdom and Japan have seen wages at the bottom and top of the skill distribution rise roughly in tandem, consistent with the job polarisation story. In other advanced economies such as Spain and France, wages at the bottom of the skill distribution have actually accelerated more quickly than at the top. The wage data for emerging markets tell a similar country-specific story (Figure 59).

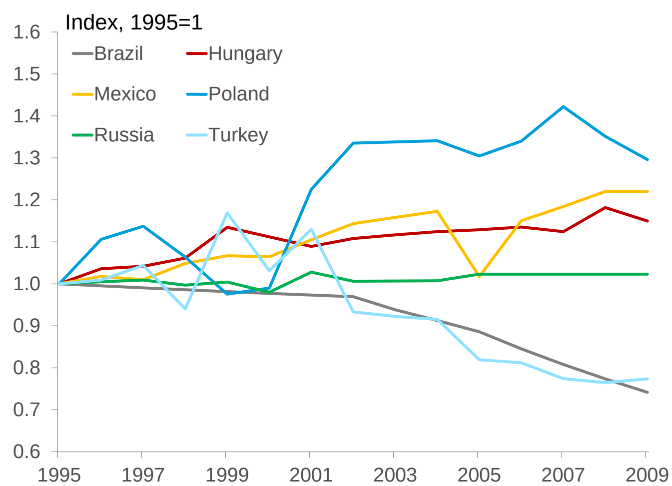
The large degree of heterogeneity of low- versus high-skilled wage trends across countries points toward institutional differences that may be playing a role. In particular, improving worker productivity from new technology is not the only force driving wage trends, especially at the bottom of the skill distribution where political-economy factors such as union participation and the generosity of unemployment compensation also likely play a determinant role.

Figure 58. Ratio of real high-skilled average hourly wage rate to real low-skilled average hourly wage rate



Note: The wage data comes from the WIOD Socio-economic Accounts, in which skills are defined on the basis of educational attainment. The hourly wage rate is calculated as total labor compensation divided by total hours worked. The wage data are deflated using national consumer price data.
Source: WIOD Socio-economic Accounts, Citi Research

Figure 59. Ratio of real high-skilled average hourly wage rate to real low-skilled average hourly wage rate

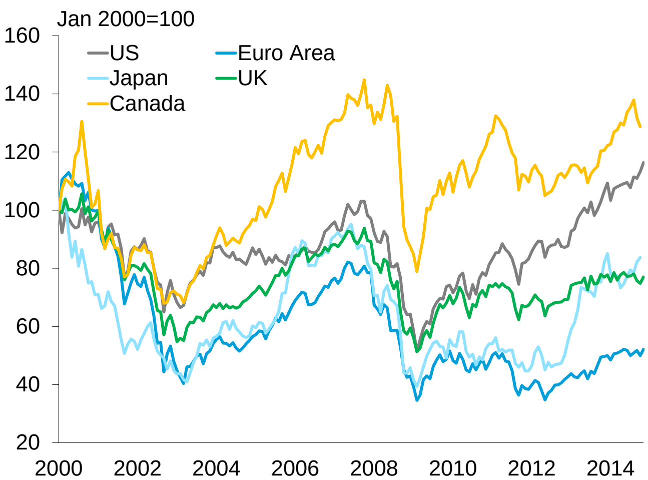


Note: The wage data comes from the WIOD Socio-economic Accounts, in which skills are defined on the basis of educational attainment. The hourly wage rate is calculated as total labor compensation divided by total hours worked. The wage data are deflated using national consumer price data.
Source: WIOD Socio-economic Accounts, Citi Research

There is some evidence that wage inequality between high- and low-skilled workers is rising in some countries because of increasing automation

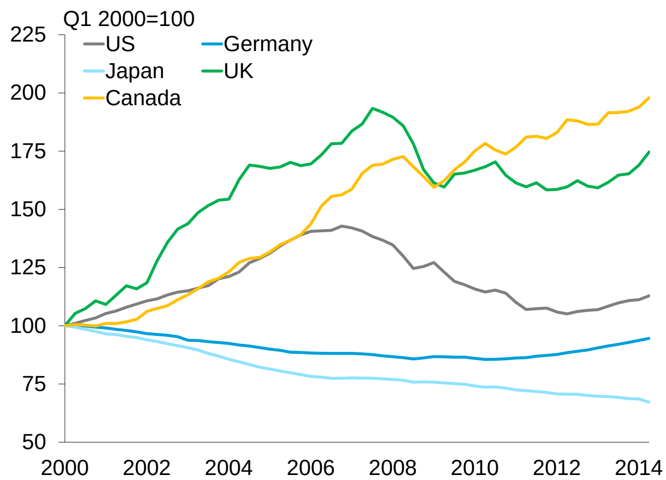
The bottom line is that there is some evidence that wage inequality between high- and low-skilled workers is rising in some countries, likely driven in part by increasing automation in the workplace. Whether this translates into persistent output gaps and chronically depressed policy rates is still an open question. It is interesting to note, however, that financial markets, which are forward looking, have to some extent priced in low interest rates well into the future. Indeed, stock prices seem high in many advanced economies (Figure 60), but not if there has been a sizeable change in the discount rate due to lower expected policy rates. Home prices, which are also sensitive to forward-looking assumptions about policy rates, are also high in some countries (Figure 61), though home price movements have been more disparate than stock price movements since the 2008 financial crisis.

Figure 60. Real values of advanced economy stock market indices



Note: US = DJIA, EA = STOXX, Japan = Nikkei 225, Canada is S&P/TSX Composite. Each is deflated by the respective national consumer price index.
Source: Haver Analytics, Citi Research

Figure 61. Advanced economy real home prices



Source: Dallas Fed, Citi Research

Even if output gaps are widening and price pressure is weakening because of technological change, these consequences will not go unaddressed by policymakers

We conclude by stressing that even if technological change has macroeconomic consequences in the form of widening output gaps and weaker price pressure, those consequences will not go unaddressed by policymakers. Central bankers may rely on additional programs of quantitative easing to boost effective demand, or they may eventually take even bolder steps such as increasing inflation targets above the roughly 2% target that most central banks currently adhere to. On the fiscal side, we are likely to see an increased effort by policymakers to deal with the large swath of workers who will inevitably be displaced by automation. Public job guarantees for those displaced could boost effective demand; and in the event that supply continues to outpace demand due to technological change, policymakers may take deliberate steps to reduce supply by implementing more work-sharing policies to spread job tasks across a broader pool of available workers.[118]

How policymakers deal with the consequences of the digital revolution will be crucial

In short, technological change never occurs in a vacuum. How policymakers deal with the consequences brought on by the digital revolution is likely to be a crucial factor influencing valuations in financial markets for years to come.

[118] For a detailed reading of the various ways in which policymakers could respond to increasing inequality from technological change, see Meyer (2014).

Opportunities

Productivity

Productivity gains of the digital age have arguably not been as great as those associated with the switch to electricity or the steam engine

The digital age has so far arguably failed to deliver the leaps in productivity associated with earlier general purpose technologies (GPTs) like electricity and the steam engine. This concern was raised as early as 1987, when Robert Solow remarked that “you can see the computer age everywhere but in the productivity statistics”. After the temporary surge in productivity growth of the late-1990s came to an end, the view that most of the benefits from the digital revolution have already been seen has gained in resonance.

This has been forcefully argued by economists like Robert Gordon, examining trends in productivity in the United States. Between 1939 and 2000, average output per person grew at 2.7%; much faster than the period before from 1891 to 1939 when average annual productivity growth was 1.5%. Since the turn of this century productivity has been even more sluggish. Over the period 2000 to 2013, productivity grew only at 0.9%.[119]

It could be that we’re not able to capture the increase in productivity that the digital economy has produced because many things the digital economy allows us to access are free

How does this square with the astounding technological advances in machine intelligence and robotics we are currently witnessing? Part of the answer may be that many of the things the digital economy allows us to access for free are not captured in the productivity statistics. Nevertheless, as Robert Gordon has pointed out, it has always taken time for official statistics to incorporate new technologies in productivity measurements. For example, between 1908 and 1929, the price of the Ford Model T declined from $900 to $265, but the automobile was not entered into the consumer price index until 1935.

The sluggish growth in productivity could just be that productivity only increases after long lags

A more refined explanation for the sluggish growth in productivity over the last decade is that technological progress increases productivity only after long lags. According to research by Chad Syverson “productivity growth during the IT era echo those observed during electrification. […] a slowdown that in the electrification era was followed by a productivity growth acceleration.”[120] Crucially, productivity surged between 1996 and 2004 as corporations started to redesign their organisations to accommodate new technologies. In particular, business process re-engineering became common practice in most firms producing manufactured goods by the mid-1990s.

The idea behind re-engineering was brought forward by Michael Hammer, arguing that: “Instead of embedding outdated processes in silicon and software, we should obliterate them and start over. We should 'reengineer' our businesses: use the power of modern information technology to radically redesign our business processes in order to achieve dramatic improvements in their performance.”[121] By the mid-1990s, about 60% of the Fortune 500 companies claimed to have done some re-engineering efforts or planned to do so, which involved economizing heavily on the middle-management workforce.[122]

More direct evidence for this surge in productivity stemming from organisational restructuring is provided by John Fernald, suggesting that the GPT characteristics of computers and complementary software technologies fostered business

[119] Gordon (2012)
[120] Syverson (2013).
[121] Hammer (1990).
[122] Rifkin (1995).

reorganisation. He further argues that his findings are “consistent with the view that benefiting from IT takes substantial intangible organisational investments that, with a lag, raise measured productivity. By the mid-2000s, the low-hanging fruit of IT had been plucked.”

Much of the benefits from the most recent development in machine learning and mobile robotics are yet to be seen

Much of the benefits from recent developments in machine learning and mobile robotics are yet to be seen. Another recent study suggests that productivity follows investment in digital technologies with lags of between 5 and 15 years.[123] As many of the technological developments we are currently witnessing, such as autonomous vehicles, are yet to be realised, and other developments in online education and medical diagnosis have just started, we are likely to see substantial future productivity gains.

Digital technologies offer much potential in traditional low productivity sectors, such as healthcare and education. In other words, services in sectors that have traditionally been associated with William Baumol’s cost disease — meaning that they experience wage growth without productivity growth, pushing costs onto consumers — may become more affordable.

The more transformative a technology, the longer it may take for individuals, organisations and economies to adapt. There is still much to be gained from the digital economy, but shifts in mindsets and organisational structures can take time.

Automation and Productivity

Jim Suva, CPA
US IT Hardware Analyst

Adopting automation technology to increase productivity and lower manufacturing costs has been the trend in the technology supply chain for several years. However, the recent increased flexibility to more easily reprogramme the automation process has enabled this trend to accelerate. One example is the evolution in technology for the wafer and semiconductor chip manufacturing sector, which has now evolved to a “lights-out manufacturing environment” wherein a factory is fully operated by machines and robots without the need for humans on-site. The development of automation significantly increased semiconductor fabrication productivity and compares to the traditional manual operating mode where humans previously touched and moved wafers through the manufacturing process, which is less precise and also involved toxic working environments for human beings.

Additional examples include the production of smart electronics using automated injection moulding with the help of vision system mounted robots, which can more precisely determine the placement, shape and density accuracy of components (metal and plastic) and inspect them faster than a human can in quality control for insert moulded parts. In addition, evolving automation manufacturing processes enable Electronic Manufacturing Services (EMS) companies to provide tailored designing capability in both high volume low mix (i.e.. consumer electronics such as smartphones or TVs) and low volume high mix (i.e. hospital and doctor medical devices) products and create value for customers. Putting pen to paper and quantifying the financial impact of this can be seen by looking at Flextronics, one of the biggest EMS companies in the world. Flextronics was able to improve its revenue per employee by 95% to $174,000 in 2014 from $89,000 in 1997 with product portfolio ranges from traditional consumer electronics to automotive smart electronics and clean tech products.

[123] Basu and Fernald (2007).

The Sharing Economy

Benefits of the emerging sharing economy are not showing up in productivity statistics, but they are real

While productivity is at the heart of long-run growth, consumer surplus is arguably a better measurement of the benefits to societal progress. Thus, even though much of the emerging sharing economy is not captured by productivity statistics, its benefits to most people are certainly real: Wikipedia, Google, Facebook, LinkedIn, Instagram and Dropbox all contribute to the sharing economy, and they are all available for free. As the sharing part of the economy is likely to continue growing as a result of digitisation, consumers along with talented entrepreneurs will be the greatest beneficiaries of the digital age.

The opportunities offered by the digital economy are immense as the Internet and smartphones make it cheaper to match supply and demand. People can now register their unused assets on various online platforms, connecting owners and users. Satellites and smartphones even make it possible for consumers to locate services nearby.

This is the idea behind a range of online services that enable people to share cars, accommodation, car-parking spaces, bicycles, musical instruments, garden equipment, household appliances and other items. Such peer-to-peer rental concepts can provide additional income for owners, while providing cheaper alternatives to consumers.

The most prominent sharing service is probably San Francisco-based Airbnb, allowing users to rent out their vacant rooms or homes to travellers around the world. Recently valued at $10 billion and with reported revenue of $250 million last year, the company shows how beneficial the sharing economy can be to talented entrepreneurs. Yet the benefits to consumers are equally substantial: the platform reached 10 million transactions last year in 192 countries.

The way Airbnb provides cheaper accommodation, car-sharing concepts provide new alternatives to commuters. While some companies, such as Buzzcar and RelayRides, offer peer-to-peer car-rental services allowing consumers to use somebody else's car for a fee, there are now also taxi-like services.[124] Companies like Uber use smartphone apps with satellite location to connect drivers and passengers, and provide a cheaper alternative to traditional taxi companies.

The sharing economy is not merely the result of digital technologies, but also from clever ways to build trust

The rise of the sharing economy is however not merely the result of digital technologies connecting people: it is as much a result of how they can be used in clever ways to build trust. A decade ago, when eBay started, people were still hesitant to provide things like their credit card details to online marketplaces. That is no longer a major obstacle. Secure Internet payment systems have been crucial, but also transparent rating systems. Home owners that register on Airbnb offering accommodation to strangers rely heavily on users' past ratings, and travellers staying in a strangers' flat can read reviews from previous guests. In addition, some services integrate Facebook, allowing users to check if they have mutual friends.

The sharing economy still has much more potential. Governments could start unlocking some public assets, like publicly owned vehicles, providing benefits to communities as well as tax payers. Furthermore, as the sharing economy allows people to access more things cheaper or even for free, leisure may also become more attractive.

[124] The Economist (2013).

A World of Leisure

In a 1932 essay entitled *In Praise of Idleness*, Bertrand Russell argued that a shorter working day would allow people to enjoy "the necessities and elementary comforts of life."[125] How could such a life be obtained? According to John Maynard Keynes, technological progress provides the answer, potentially solving mankind's "economic problem", and depriving us of our traditional purpose of subsistence. Instead he predicted that we could eventually be facing the dilemma of how to use our freedom from economic cares and occupy our leisure.[126]

In the past, the wealthy elite have enjoyed the most leisure, while the poor needed to work relatively hard for their subsistence. According to research by Hans-Joachim Voth, average hours worked increased in Britain during the early Industrial Revolution, from 50 to 64 hours per week between 1760 and 1800.[127] At the time, Jane Austen's novels about the wealthy elite depicted a society at leisure.

The number of leisure hours in the US has increased for low-educated men but decreased for high-educated workers

Yet, over recent decades, things have been different in developed economies. Not only have average working hours declined, but the wealthy are now the ones working relatively long hours. According to a recent study, leisure in America increased by 6 to 8 hours per week for men and 4 to 8 hours for women between 1965 and 2003.[128] Furthermore, research shows that low-educated men saw their leisure grow between 2003 and 2007, while highly-educated workers saw their leisure decline. More recent data from the American Time Use Survey 2013 also show that workers with at least a bachelor's degree work on average two hours more per day than high-school graduates.[129]

Other countries are seeing similar trends

This is not a trend that is specific to America. For the countries where data are available, the vast majority of people today work fewer hours than they did in 1990. Western Europeans, who worked more than Americans as late as 1960, now work much less suggesting that unionisation and labour market regulations are partly behind the decline in hours.[130] Leisure is seemingly also associated with productivity-increasing technological progress. Workers in Greece put in the most hours in the OECD: they work more than 40% more than Germans, for example. Yet German productivity is about 70% higher, more than making up for the difference.[131]

Technological change also partly explains why low-income workers enjoy more leisure. An important feature of the digital age is that it provides many things for free, giving low-income earners a more enjoyable leisure. According to a study by Daniel Kahneman, Alan B. Krueger, David Schkade, Norbert Schwarz, and Arthur A. Stone "people with greater income tend to devote relatively more of their time to work, compulsory non-work activities (such as shopping and childcare), and active leisure (such as exercise) and less of their time to passive leisure activities (such as watching TV)." As information technology makes especially passive leisure more interesting and cheaper, the demand for leisure among low-income earners is likely to increase further. Companies like Netflix and Spotify have recognised this trend, and many others are following.

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[125] Russel (1932).
[126] Keynes (1930).
[127] Voth (2001).
[128] Aguiar and Hurst (2007).
[129] The Economist (2014).
[130] Alesina, Glaeser, Sacerdote (2006).
[131] The Economist (2014).

Skill-biased technological change may also have induced skilled workers to work more. According to research by Peter Kuhn and Fernando Lozano, for example, the rise in hours worked by highly-educated men between 1980 and 2000 is primarily driven by the premium associated with working longer hours, incentivising especially skilled workers to increase their labour supply.[132]

To be sure, the growing leisure among low-skilled workers is not all good news, as some of it may be involuntary, caused by unemployment.[133] But information technology is undoubtedly making leisure more attractive for ordinary people.

[132] Kuhn and Lozano (2008)
[133] Aguiar and Hurst (2007).

6. Adapting to Technological Change: Pathways and Strategies

"The fundamental impulse that sets and keeps the capitalist engine in motion comes from the new consumers' goods, the new methods of production or transportation, the new markets… [This process] incessantly revolutionises the economic structure from within, incessantly destroying the old one, incessantly creating a new one. This process of creative destruction is the essential fact about capitalism."[134]

The digital age may be more disruptive than previous revolutions as it is happening faster and is fundamentally changing the way we live and work

Technological change is at the very heart of the creative destruction described by Joseph Schumpeter. While revolutionary technologies of the past have created enormous wealth, they have also been a source of disruption. The digital age may cause more upheaval than previous technological revolutions as it is happening even faster and is fundamentally changing the way we live and work.

Yet technology is not destiny. With the right understanding of associated challenges, and the right strategies, the digital age may be an inclusive one. To be sure, there are profound economic risks associated with the rapid technological change that is currently taking place. Surging inequality is not only dividing societies, it is also threatening macroeconomic stability. As digital technologies do not require much capital investment, and mainly benefit those with a lower propensity to spend — leading to reduced investment and consumption — the digital age could also become a period of secular stagnation.

Skilled workers have benefited from the digital age as producers while unskilled workers have benefited as consumers

While the digital age has so far mainly benefited skilled workers as producers, it has also benefited unskilled workers as consumers, making their leisure more interesting and self-fulfilling. A surge in productivity, as organisational structures are redesigned to accommodate new technologies, could make up for some of the fall in investment and consumption, and together with policies designed to boost aggregate demand and reduce inequality, growth rates could rebound and even surge.

In this chapter we will emphasise the need for countries to adapt to these trends in an inclusive manner. To achieve greater equality, and avoid the threat of secular stagnation, governments have to understand the direction and pace of technological change and plan for the long term.

Planning for the Long Term

When is this happening? Soon

In considering future technological development, one question hangs over our predictions: when? Specifically, what is the timeline over which anticipated impacts of technological change will unfold? The most concise answer to this question is simply: soon. The technologies we discuss, from autonomous vehicles to algorithmic sales assistants, are largely already available within research labs: any uncertainty is due less to the surrounding rates of technological development and more to questions of adoption. Nonetheless, this uncertainty is still considerable, due to two variable and regionally-dependent influences. As a first concern, adoption of labour-saving inventions will be influenced by the availability of cheap labour. Secondly, technological adoption may be slowed by regulatory concerns and political activism. Protests from traditional taxi companies, along with public concern, has been at the root of resistance to the app-based company Uber, which has now received cease-and-desist orders in Brisbane, Frankfurt and Taiwan, and

[134] Schumpeter (1942, p. 83)

which has closed down its Spanish operations entirely. Another related obstacle to technological deployment is found in software patent "trolls", whose claims on ill-defined patents are estimated to have directly cost firms $29 billion in 2011.[135]

Predictions on the influence of technologies yet undeveloped are difficult

In casting our minds ahead to the influence of technologies yet undeveloped, we face the difficulties[136] associated with forecasting technological progress. These difficulties are particularly profound in speculating about the development of machine intelligence competitive with human labour: the field of Artificial Intelligence (AI) has a poor record in predicting when human-level intelligence may be algorithmically possible. Examples of unsuccessful predictions range from the expectation that AI could be solved during a 2 month, 10 man, summer project in Dartmouth in 1956, to AI pioneer Marvin Minsky's claim in 1970 that "in from three to eight years we will have a machine with the general intelligence of an average human being". The question of when human-level AI will arrive features many characteristics of problems that are difficult to predict.[137] Feedback on the success of prediction is largely unavailable; the problem is difficult to decompose; and progress in AI is, to some extent, dependent on surprising insights. Despite these difficulties, we can, nonetheless, reasonably expect that human-level AI is not impossibly remote. The most recent and comprehensive survey of AI experts[138] concludes that we will probably (with over 50% probability) reach overall human ability in machine intelligence by 2040-50, and very likely (with 90% probability) by 2075.

Clearly, however, we will not need to wait for these forecasts to be tested to see the employment impact due to intelligent machines. In particular, just as the typing pool was replaced by word-processing software unable to understand what was being typed, technology will continue to substitute for human labour by simplifying the task to be performed. A recent example is found in Kiva Systems, which automated the moving of objects around a warehouse by simplifying the navigation task: bar code stickers were placed on the floor to inform robots of their precise location.[139] At all stages en-route to true human-level AI, we expect to see technologies that will radically alter the nature of work. For governments to adequately respond to these trends, a shift in mindset, investment and policies is needed. As around 47% of jobs are at risk of displacement by technologies that are largely already available that shift needs to happen sooner rather than later.

Tax Wedges and Active Labour Market Policies

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The fast-changing world of employment increases the risk that more and more workers would be left behind over time, which is at the heart of some of the risks and negative implications of the digital revolution. But there are a number of labour market policies that could potentially limit some of those negative implications. We can think of them in two broad categories: first, policies that reduce the cost of labour, or, conversely increase labour income. And second, policies that make it easier to find jobs.

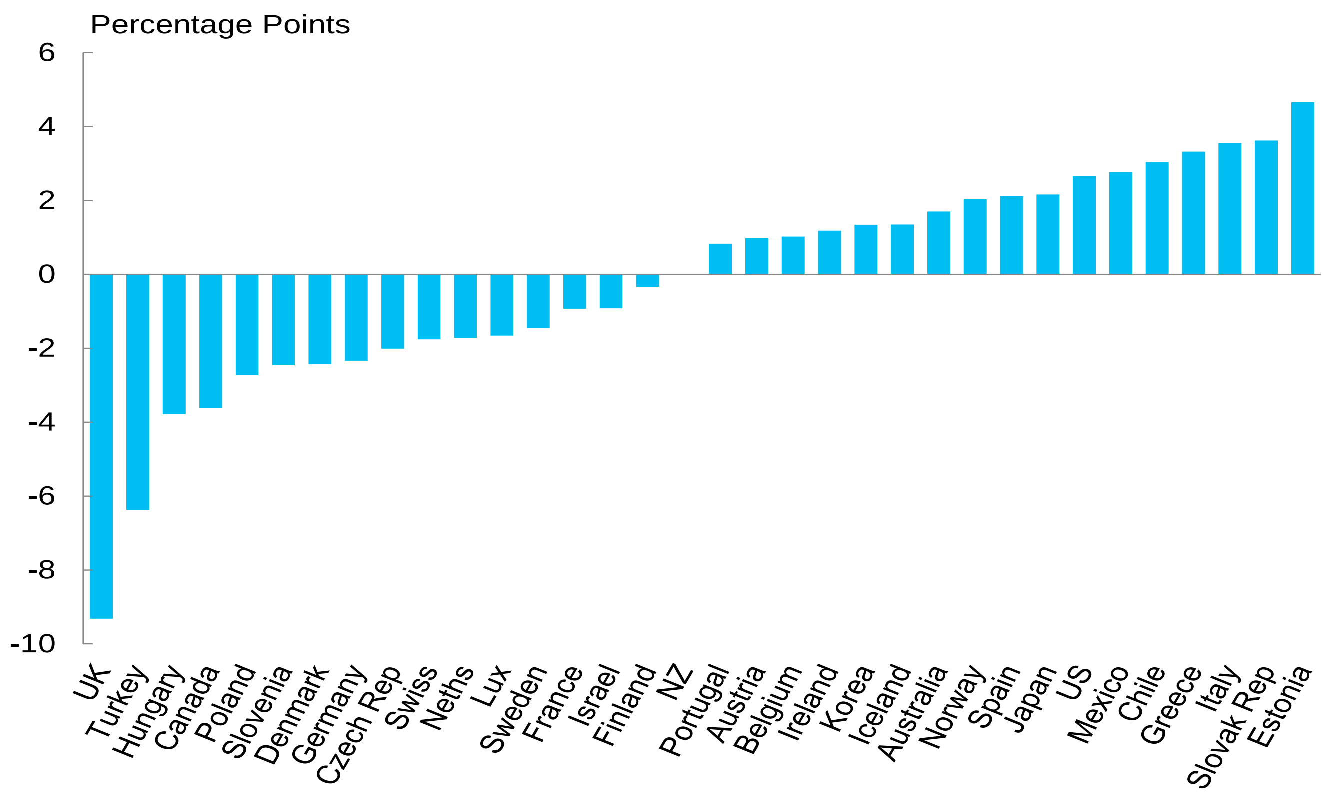
Tax wedges — the difference between the gross labour costs and 'take-home pay' — can be very large

We highlighted earlier in the report that the number of workers on low wages will likely increase as a result of 'job polarisation' – in fact, in some countries, such as the UK, it has already increased noticeably in recent years. If wages are already low, it would make sense to at least make sure that most of the cost of labour ends

[135] Bessen, J., & Meurer, M. J. (2014).
[136] Armstrong, Sotala, and Ó hÉigeartaigh (2014).
[137] Armstrong, Sotala, and Ó hÉigeartaigh (2014).
[138] Müller and Bostrom (2015)
[139] Guizzo, 2008.

up in the pockets of the workers. However, in practice, the so-called tax wedges — the difference between gross labour costs and 'take-home pay' — can be very large, particularly in a number of European countries. The tax wedge is composed of employers' and employees' social security contributions and personal income taxes. In Belgium, France or Hungary it is around a staggering 50% of total labour costs for low-wage earners (i.e. earning 67% of the average wage) according to OECD data. Significantly lowering tax wedges can be an effective way to boost take-home pay (for unchanged gross labour costs) or raise employment (if gross labour costs fall) and likely a combination of the two.

Figure 62. Change in tax wedge between 2007 and 2012 (for single person at 67% of average earnings, with two children)



Source: OECD

The UK has made efforts to lower the tax wedge, but it has increased over the past 5 years in more than half the OECD countries

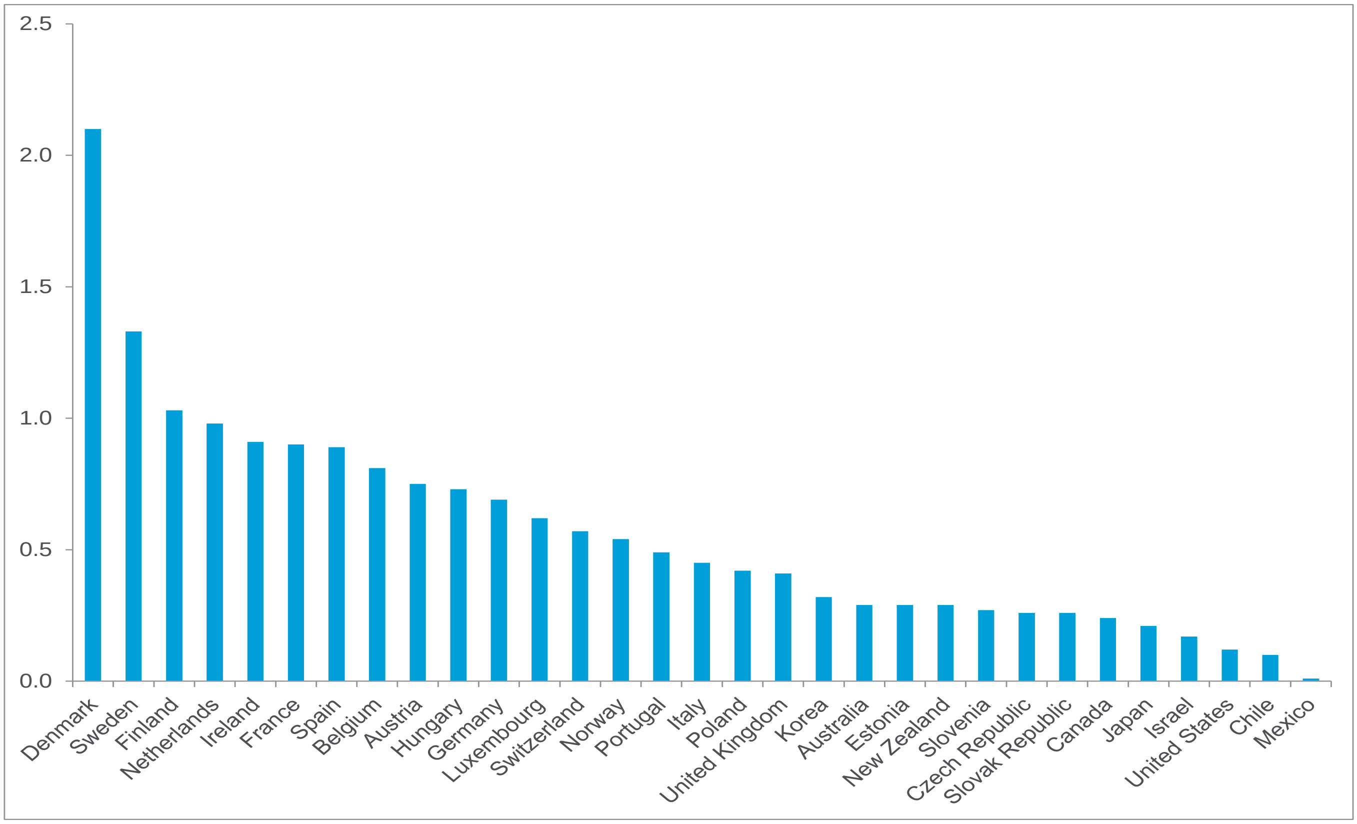
This is indeed what the UK has done in recent years. Between 2007 and 2013, the UK lowered the tax wedge by almost 9 percentage points for low-wage earners (meaning that low-wage earners now keep 9 percentage points more of their wages than previously), more than in that in any other OECD economy. In fact, in roughly half the OECD countries, the tax wedge *rose* over this period, including in some of the fiscally challenged countries such as Spain, Greece, or Italy, but also in Japan and the US (Figure 62). The fall in tax wedges is surely not the only reason why job growth in the UK has been above the industrial country norm in recent years, but it has surely contributed.

ALMPs are aimed at helping and providing incentives for the unemployed to find gainful employment

Active labour market policies (ALMPs, such as job placement services, benefit administration, special labour market programmes and training) instead are aimed at helping and providing incentives for the unemployed to find gainful employment. Active labour market policies are an integral part of the 'flexicurity' model of labour markets of the Scandinavian countries and there is some evidence that, if done right, active labour market policies can be an efficient way to keep employment levels high and keep long-term unemployment low.[140]

But the extent to which ALMPs are used varies quite widely across different countries (Figure 63). For example, in Denmark, ALMP spending amounted to more than 2% of GDP in 2012, according to OECD data, roughly 1% of GDP in the Netherlands, France and Germany, but less than 0.5% in Italy, Portugal and the UK. In many of these countries, ALMP spending remains relatively unchanged compared to the level of ALMP spending in 2007, when unemployment was generally much lower (but fiscal coffers were fuller).

Figure 63. Expenditure on Active Labour Market Policies (% of GDP)



Source: OECD

Will Taxation Have to Change to Adapt to the World of Work in the 21st Century?

Changes in the nature of work going forward will have an effect on fiscal costs

The changes in the world of work that we describe can have large fiscal costs for two reasons. First, to the extent that average wage growth is suppressed and unemployment raised, tax receipts will suffer. Second, some potential policy responses to ameliorate the adverse effects of the changes in the structure and nature of employment (such as expanding active labour market policies or lowering tax wedges, or increased spending on education or social spending) will likely carry substantial fiscal costs, too. Unlike in the past where such policies were sometimes dialled up in a downturn, the new structure of work may imply that such policies may need to be adopted much more consistently and in greater scope.

140 See e.g. European Commission (2006) and Boone and van Ours (2004)

Money to fund the gap can be generated by raising top marginal income tax rates, introducing wealth taxes or taxing goods and services used primarily by the wealthy

But in times of high (and often still-rising) public debt, an appropriate follow-up question would be where the resources can be found to fund such additional spending? The answer to this question is not obvious. This is despite the fact that in principle there are several fairly obvious *candidates*. Our analysis has shown that there are, of course, beneficiaries of the changes we describe. Some of the potential options to generate the money to fund additional spending could come from raising taxes on the better-off. In principle, this could happen by raising top marginal income tax rates, increasing capital income tax rates, raising corporate income taxes, introducing some form of wealth taxes or taxing goods or services that are primary consumed by the wealthy more heavily.[141]

Such changes in taxation would seem sensible to us, but they would also be a reversal of the trends of the last few decades. The OECD notes that top statutory personal income tax rates have fallen significantly in each of the three decades between 1980 and 2010.[142] In 2010, the OECD average top statutory personal income tax rate was 41.7%. In 1981, it was 65.7%. Corporate income taxes have also fallen in recent decades, from 49% in 1981 to 32.5% in 2013.

However, some of these trends may already be reversing. A number of countries already increased their top personal income tax rates in recent years. There is no sign of headline corporate income tax rates rising systematically across countries. But significant efforts are under way to close loopholes in the current fiscal arrangements for corporates, to make life harder for tax havens and to tackle tax evasion and avoidance more effectively.

Piketty famously called for global wealth taxes in 2014

Could wealth taxes be the solution? Thomas Piketty made headlines in 2014 when he famously called for global wealth taxes as one of the main policy responses to rising (income and wealth) inequality. Piketty called for a tax of 1% on wealth of between €1-€5 million, 2% on wealth of €2-€5 million (and a much higher tax on even larger fortunes), and even the IMF has noted that a wealth tax may be appropriate in some circumstances. Yet outside of extreme circumstances there have been few (and usually only timid) attempts to increase the taxation of financial or real property in recent years (and they are quite rare in history). Similarly, the taxation of capital income has become increasingly prominent in policy discussions and speeches, notably the special treatment offered to particular types of capital income (such as for 'carried interest' of private equity owners). In his recent State of the Union address, US President Obama once more called for increases in capital income taxes and for abolishing some of these privileges. Yet we have seen very little in the way of an effective increase in the taxation of capital income anywhere.

Wealth taxes could be a solution but they are difficult to design, costly to administer and relatively easy to evade

One of the reasons why wealth taxes have not been raised more widely is that they are difficult to design, costly to administer and often relatively easy to evade. For ad-hoc wealth taxes, the risk is that households would fear that such taxes could be imposed again in the future. For financial assets, a major risk is that the capital will simply find a home elsewhere — a growing issue in a world of global financial mobility and still-increasing financial interdependence. Wealth taxes would therefore be much more likely to be effective if they were imposed globally (as Piketty argues). The same applies for corporate income and capital income taxation, but we see little scope for such an initiative in a world where global leadership is rare in any area, not least against what would likely be fierce lobbying.

[141] Another direction would be to reduce other government expenditures. Given historically high ratios of government expenditure to GDP in many countries, this route strikes us as eminently sensible, but is outside the scope of this section.
[142] See OECD (2011), "Taxing Wages"

Making Growth Inclusive

Tax reform is part of the answer to making growth inclusive again…

A key challenge of the 21st century will be to make growth inclusive again. Tax reform provides part of the answer. At a time when the ever falling cost of computing makes it cheaper to displace workers with technology, while consumers benefit from declining prices of many products and services, shifting tax burdens from labour towards consumption would be a step forward. For example, a reduction in income and payroll taxes would make it cheaper to hire, while a luxury tax on positional goods could make up for some of the fall in tax revenues.

Taxes can also be shifted from labour towards wealth, including capital and income from assets. As proposed by Thomas Piketty, the wealth gap that has emerged between owners of capital and those who rely on their labour could be combatted by a global wealth tax. Although such a tax is unlikely to get implemented, some proposals are underway. In Europe, a financial transaction tax has been put forward and in the UK a tax on mansions worth over £2 million has also been proposed. In addition, tax avoidance, evasion and loopholes are also being explored.

…but it is crucial that the tax system channel funds into public investment that boost growth in an inclusive manner

It would be a mistake, however, for governments to focus too narrowly on the redistribution of income. Although taxation as such can clearly help combat inequality, the crucial task of the tax system must be to channel funds into public investment that boosts growth in an inclusive manner. As has been highlighted in this report, the main risk for both investors and workers is a future of secular stagnation, driven by a decline in the demand for new goods and services. Such a scenario can only be avoided by embracing technological progress, while making the right investments to create growth and new employment opportunities. As shown by Thomas Piketty himself, a faster growth rate reduces the importance of wealth in a country, while sluggish growth will increase it. Technological progress is thus an essential ingredient of inclusive growth: while it creates new income it also destroys old wealth.

Promoting self-employment could be a good way for governments to capture the opportunities created by the digital revolution

To ensure continuous creative destruction governments need to capture the opportunities created by the digital revolution. Crucially, while digital technologies are making tasks previously confined to labour automatable, they are also making it cheaper for entrepreneurs to start their own business: e-entrepreneurship typically requires less capital investment, and digital technologies allow people in deprived areas to reach global markets, as even more traditional goods are made increasingly mobile. In other words, digital technologies have made self-employment an option to a growing share of workers. As recent survey evidence also shows that people in self-employment were more content in their working lives, there are good reasons to believe that more people will choose to start their own business. Indeed, the future of work may well be one where self-employment is the new normal. The main challenge for economic policy is thus to encourage more entrepreneurial risk-taking. Reducing red tape and implementing tax systems that do not discourage self-employment is crucial, but building welfare systems that cap the downside to entrepreneurial failure may also help.

Inclusive growth requires more investment in skills and training to prepare workers for the jobs of the future

Nevertheless, as technology is increasingly taking the form of capital that displaces labour, technological progress also risks leaving many people behind. According to research by Carl Benedikt Frey and Michael Osborne, as many as 47% of US jobs are at risk of automation over forthcoming decades. Inclusive growth thus requires fostering creative destruction while ensuring that ordinary workers are able to shift into new job opportunities as existing occupations and industries are being eroded. To successfully manage this transition, more investment in skills and training is required to prepare workers for the jobs of the future.

Public investment in promising technologies for the future could help drive job creation

Predicting the type of new jobs that will emerge is notoriously difficult. Nobody in the early 20th century would have predicted many of the jobs and industries we have today, including software engineering, tourism and nanotechnology. Yet, we do have some idea of the type of jobs that are emerging. Big data architects, cloud services specialists, iOS developers, digital marketing specialists, and data scientists, are all occupations that barely existed on LinkedIn only five years ago, resulting from new technologies.[143] Public investment in promising technologies for the future could help drive job creation too. Solar energy systems engineers, wind energy engineers, informatics nurse specialists, bioinformatics scientists, and biomass plant technicians are new and emerging occupational titles, where public spending could help facilitate new job creation. To be sure, these are all very different jobs, but they share one common characteristic: they are significantly more skilled than most jobs of the past. Although education alone is unlikely to solve the problem of surging inequality, it remains the most important factor.

Transforming Education

The surging cost of education is the main hurdle for workers to adapt to technological change

While the concern over technological unemployment has so far proven to be exaggerated, the reason why human labour has prevailed relates to its ability to acquire new skills. Yet this will become increasingly challenging as new work requires a higher degree of cognitive abilities. At a time when technological change is happening even faster, a main hurdle for workers to adapt is thus the surging costs of education. In Europe, for example, education is increasingly putting pressure on government budgets, leading countries like Britain to pass on a growing share of the costs to students. In America, this has been common practice for some time — public American universities increased their fees by 27% between 2007 and 2012, while fees in private non-profit universities rose by 28% over the course of the decade leading up to 2012. Alarmingly, American student debt now amounts to $1.2 trillion, leaving many students with gloomy future prospects as they enter a faltering labour market.[144]

Much of the recent surge in fees stems from an increasing share of resources being absorbed by administration. According to The Goldwater Institute, the cost of administration among America's leading universities has been growing substantially faster than budgets for teaching and research activities: between 1993 and 2007 the number of teachers and research staff per 100 students grew by 18%, while the number of full-time administrators surged by 39%.

The digital age can help to transform education by lowering costs

Fortunately, in the way the digital age is transforming the world of work, it can help transform education as well. Cost reductions to make education more accessible, without putting additional pressure on government budgets, can be achieved through online education. At Georgia Tech, for example, a new online master's degree in computing costs less than a third of an on-campus degree — $7,000 instead of $25,000.[145] Costs are also likely to decrease further as online education makes more big data readily available, allowing an increasing share of administration work to be automated.

MOOCs have already started the transformation

To be sure, MOOCs (Massive Open Online Courses) are already transforming both schools and higher education. The virtual Khan Academy, for example, already has about 10 million users, making it the world's largest school. Yet, red tape often inhibits the diffusion of new educational models. For example, a key challenge in the US for education technology companies remains distribution. Vendors in the US

[143] Frey (2014)
[144] The Economist (2014).
[145] Ibid.

have to navigate a byzantine labyrinth of a system spanning 50 state education agencies, 14,000 school districts each with a varying approach to procurement, and upwards of 65,000 individual schools. A survey conducted by the education industry association found that only 23% of education tech providers are satisfied with the ability to gain visibility in a school district. InBloom, a well-funded non-profit education tech start up supported by the Bill and Melinda Gates Foundation, was recently wound up. Alternatively News Corp has invested approximately $1.1 billion in its Ed Tech division Amplify since 2010 and has yet to see a significant return in terms of revenue, with just $130 million forecast in 2015. The pace of technological change within schools remains slow.

In higher education things are progressing faster, although critics often point at the drop-out rates associated with online courses, which often exceed 90%. Yet, these numbers need to be put in perspective. Many leading universities accept fewer than 10% of their applicants. The few students that are accepted and have a high propensity to pass constitute only a fraction of the number of students that apply. MOOCs, on the other hand, are accessible to all potential students, and there is virtually no cost associated with starting a new course while looking for employment.

MOOCs further have the potential to make geography less important as students can access the best content and teachers regardless of their location. For example, of the 155,000 students who registered for MIT's prototype Circuits and Electronics course, most came from America, Colombia, India, Britain, and Spain.[146] Thus, students in deprived areas and relatively poor countries are now able to access some of the best classes in the world, making even high-end education an option for many students that could previously not afford it.

MOOCs have the ability to increase productivity by making time a redundant factor in education

Perhaps the most promising aspect of MOOCs is their potential to increase productivity by making time a redundant factor in contemporary education. As has been forcefully argued by Clayton Christensen, students with different learning requirements no longer need to conform to rigid academic programmes which span over a specified period of time.[147] This form of factory-based education that emerged in the 19th century, following the industrial revolution, is seemingly out of date. Today, students with different backgrounds and learning requirements can complete courses at their own pace. On campus lectures have no pause, rewind or fast-forward buttons, but MOOCs allow students to learn in ways that suit them the best. Students can skip some lectures while attending others several times at virtually no additional cost. They can also take assessments as many times as necessary until they have gained their desired proficiency in a subject or acquired a new skill. In other words, digital technologies allow time to become the variable factor while learning is fixed.

Making time a variable factor in education would also make it easier for people to acquire skills later in life. In particular, at a time when technology is making the skills of many workers redundant at a faster pace than perhaps ever before, new approaches to life-long learning will be essential. This is suggested by the fact that higher-education enrolment among people aged 35 or above has increased substantially in America over recent decades. In the 1990s, 314,000 students aged 35 or above enrolled at an institution for higher education. In the 2000s, the equivalent figure was 899,000.[148] By breaking down the learning process, leaving students with a menu of skills and competencies they can chose to acquire without

[146] The Economist (2012).
[147] Christensen and Eyring (2011).
[148] The Economist (2014).

necessarily completing a standardised academic programme, MOOCs can provide modularised approaches to education that appeal to employers looking to retrain their workforce.

Online learning can both reduce costs and improve the quality of education

Online learning does not only offer the potential to reduce costs, it can also help improve the quality of education. With more students signing up, big data approaches make it easier to evaluate the students' learning process, and measure their progress. This success has been partially due to new structural innovations, particularly the semi-synchronous nature of the courses, but future prospects rest upon MOOCs' increasing use of data and machine learning algorithms. MOOCs already make use of big data detailing how students interact on forums, their diligence in completing assignments and viewing lectures, and their ultimate grades.[149] This data will ultimately allow for algorithms that act as interactive tutors, with teaching and assessment strategies statistically calibrated to match individual student needs.[150] These advances will permit the global access to high quality, interactive, education that is needed to prepare students for the future workforce.

A recent study comparing a MOOC in physics at the Massachusetts Institute of Technology (MIT) to its equivalent on-campus course on the same subject found that the MOOC student actually learned more than they normally would during a regular lecture.[151] Nevertheless, MOOC students compared poorly in group work, suggesting that interactive face-to-face learning methods are still important in fostering many of the soft skills demanded by employers.

Despite its positive impact, online education will unlikely be a full substitute for on-campus teaching

Online education is thus unlikely to fully substitute for on-campus teaching. Physical interactions between students (and between students and teachers) are likely to become even more important, as social, creative and problem-solving skills will be essential in most developed labour markets. Nevertheless, as online courses provide unprecedented access to knowledge at much lower costs, and improved methods of learning, the productivity gains will likely be substantial.

[149] Simonite (2013); Breslow et al., (2013).
[150] Woolf (2010).
[151] Colvin et al. (2014).

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No other university or institution hosts a research body like the Oxford Martin School. Our community of more than 300 researchers, from Oxford and beyond, is working to address the most pressing global challenges and opportunities of the 21st century. The great challenges of our time share one feature. They cannot be understood and tackled by any one academic field alone. This common factor makes these challenges difficult for individuals, businesses, governments and societies to address. Each Oxford Martin School research programme brings together academics from different disciplines to provide fresh perspectives on complex global issues. These include the future of the global financial system, cybersecurity, demographic change, the future of food and farming, the implications and mitigation of climate change, and the applications of innovation in healthcare. The unifying criteria for membership of the School are that, to qualify for its support, research must be of the highest academic calibre; must tackle issues of a global scale; could not have been undertaken without the School's support; and must have a real impact beyond academia.

The School was founded in 2005. It was made possible through the vision and generosity of Dr James Martin (1933-2013). Dr Martin believed that this century, and specifically the next two decades, will be a crucial turning point for humanity. He understood that we now have the power to destroy possibilities for future generations but, equally, we have the potential to improve dramatically the wellbeing of people across the planet. It is this combination of urgency and optimism that characterises all the work at the Oxford Martin School.

Oxford Martin School faculty have demonstrated a strong record in informing thinking on significant global policy issues, focusing on critical gaps where the School's innovative research and interdisciplinary ethos are uniquely placed to influence decision making. At the global level, the School's experts are engaged with numerous international agencies and activities, advise multinational businesses and are involved in policy formulation in over twenty countries. They have helped develop alternatives to tackling climate change beyond the Kyoto Protocol; provided advice to the World Health Organization on understanding and combating dangerous global pandemics; and contributed to new rules to improve global financial stability. In the United Kingdom, Oxford Martin School academics regularly provide expert testimony to parliamentary hearings and have been advising the Prime Minister and cabinet members on strategic science and technology policy issues. The Oxford Martin School regularly works in partnership with governments, the private sector, think tanks and inter-governmental and non-governmental organisations.

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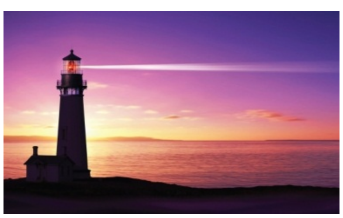

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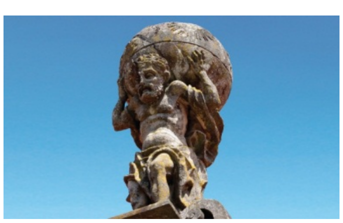

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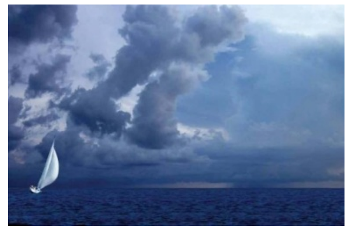

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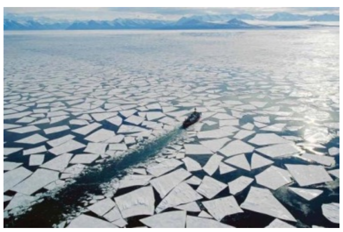

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Key Insights regarding the future of Innovation and Employment

LABOUR MARKET

Low-skilled workers benefited in the 19th century during the Industrial Revolution, while skilled workers have been the main beneficiaries of technological progress in the 20th century through the Computer Revolution. / As the scope of automation is increasing, intelligent robots with enhanced senses and dexterity are now able to perform a much broader scope of non-routine manual tasks, jeopardizing low-skill jobs and industries otherwise thought to be safe from automation.

SHIFTING WEALTH

In the Industrial Revolution, people benefited both as producers and consumers over the long run. / So far, the digital age has been the age of capital rather than the era of labour. Digital technologies increasingly substitute for labour meaning that innovators and entrepreneurs, not workers or investors, will be the main beneficiaries.

TECHNOLOGY

Historically, countries have adopted a new technology on average 45 years after its invention. / Adoption lags are falling away with new technology being adopted faster than ever before and changing how we live and work.