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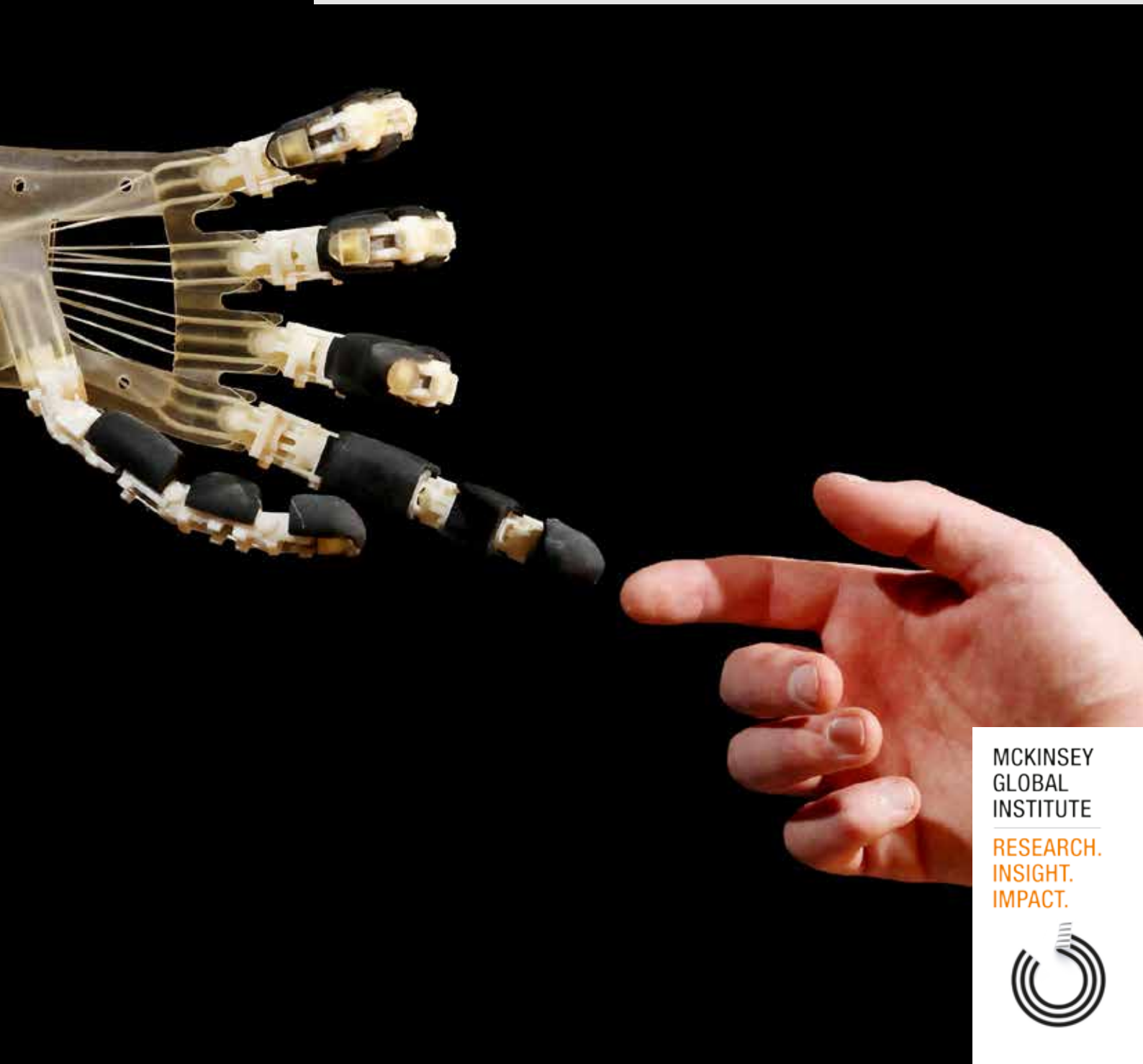
A FUTURE THAT WORKS: AUTOMATION, EMPLOYMENT, AND PRODUCTIVITY

JANUARY 2017



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A FUTURE THAT WORKS: AUTOMATION, EMPLOYMENT, AND PRODUCTIVITY

JANUARY 2017

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PREFACE

Automation is an idea that has inspired science fiction writers and futurologists for more than a century. Today it is no longer fiction, as companies increasingly use robots on production lines or algorithms to optimize their logistics, manage inventory, and carry out other core business functions. Technological advances are creating a new automation age in which ever-smarter and more flexible machines will be deployed on an ever-larger scale in the workplace. In reality, the process of automating tasks done by humans has been under way for centuries. What has perhaps changed is the pace and scope of what can be automated. It is a prospect that raises more questions than it answers. How will automation transform the workplace? What will be the implications for employment? And what is likely to be its impact both on productivity in the global economy and on employment?

This report was produced as part of the McKinsey Global Institute's overall research on the impact of technology on business and society, and specifically our ongoing research program on the future of work and the potential impacts on the global economy of data and analytics, automation, robotics and artificial intelligence. In this report, we analyze how a wide range of technologies could potentially automate current work activities that people are paid to do in the global workforce, and what the impact could be on global productivity. This work does not define what the new activities and occupations that will be developed will be, nor does it analyze in depth how the economic gains of automation will be distributed or provide specific policy recommendations for governments. While we consider a broad range of automation technologies, we do not focus specifically on any particular technologies. We realize that this area of research is evolving rapidly, given the pace of technological advancement, and we plan to update the perspectives presented in this report regularly.

The research was led by James Manyika, a director of the McKinsey Global Institute and McKinsey senior partner based in San Francisco; Michael Chui, an MGI partner in San Francisco; and Mehdi Miremadi, a McKinsey partner based in Chicago. MGI and McKinsey senior partner Jacques Bughin and McKinsey senior partners Martin Dewhurst, Katy George, Andrew Grant, Bill Schaninger, Stefan Spang, and Paul Willmott guided and contributed to the research. We would especially like to acknowledge the work of Sean Kane, Rick Cavolo, and Tong Chen, who each headed the research team at different times over the course of the two-year project and who played invaluable roles in coordinating and driving it forward. The team comprised Anuj Abrol, Jared Barnett, Jackson Beard, Lily Cheng, Josh Cogan, Arielle Copeland, Sam Doniger, Rachel Garber, Paul Gilson, Bob Glied, Sartaj Grover, Gauri Gupta, Benjamin Harrison, Alex Hinch, Tanay Juipuria, Daniel Langer, Kunal Mehta, Andrey Mironenko, Vaishal Patel, Steven Pecht, Jonathan Sands, Santhosh Suresh, Adam Tourgee, Roshin Unnikrishnan, Jean Xin, Roger Yang, Gordon Yu, and Vicki Yu.

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Many other external experts informed our research, including those whom we surveyed about the timing of technological progression. We are deeply grateful for their insight and assistance. In addition, our research has benefited from the work of other researchers, including Daron Acemoglu, David H. Autor, Erik Brynjolfsson, Carl Benedikt Frey, Jason Furman, Andrew McAfee, Michael Osborne, and Tim O'Reilly.

This report contributes to MGI's mission to help business and policy leaders understand the forces transforming the global economy, identify strategic locations, and prepare for the next wave of growth. As with all MGI research, this work is independent and has not been commissioned or sponsored in any way by any business, government, or other institution. While we are grateful for all the input we have received, the report is ours, including any errors. We welcome your comments on this research at **MGI@mckinsey.com**.

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January 2017

A restaurant in Yiwu, Zhejiang province of China.
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Technology is advancing rapidly

A vision of future automation

Humans will interact more with machines

IN BRIEF

A FUTURE THAT WORKS: AUTOMATION, EMPLOYMENT, AND PRODUCTIVITY

Advances in robotics, artificial intelligence, and machine learning are ushering in a new age of automation, as machines match or outperform human performance in a range of work activities, including ones requiring cognitive capabilities. In this report, part of our ongoing research into the future of work, we analyze the automation potential of the global economy, the factors that will determine the pace and extent of workplace adoption, and the economic impact associated with its potential.

- Automation of activities can enable businesses to improve performance, by reducing errors and improving quality and speed, and in some cases achieving outcomes that go beyond human capabilities. Automation also contributes to productivity, as it has done historically. At a time of lackluster productivity growth, this would give a needed boost to economic growth and prosperity and help offset the impact of a declining share of the working-age population in many countries. Based on our scenario modeling, we estimate automation could raise productivity growth globally by 0.8 to 1.4 percent annually.
- About half the activities people are paid almost $15 trillion in wages to do in the global economy have the potential to be automated by adapting currently demonstrated technology, according to our analysis of more than 2,000 work activities across 800 occupations. While less than 5 percent of all occupations can be automated entirely using demonstrated technologies, about 60 percent of all occupations have at least 30 percent of constituent activities that could be automated. More occupations will change than will be automated away.
- Activities most susceptible to automation involve physical activities in highly structured and predictable environments, as well as the collection and processing of data. In the United States, these activities make up 51 percent of activities in the economy accounting for almost $2.7 trillion in wages. They are most prevalent in manufacturing, accommodation and food service, and retail trade, and include some middle-skill jobs.
- Technical, economic, and social factors will determine the pace and extent of automation. Continued technical progress, for example in areas such as natural language processing, is a key factor. Beyond technical feasibility, the cost of technology, competition with labor including skills and supply and demand dynamics, performance benefits including and beyond labor cost savings, and social and regulatory acceptance will affect the pace and scope of automation. Our scenarios suggest that half of today's work activities could be automated by 2055, but this could happen up to 20 years earlier or later depending on the various factors, in addition to other wider economic conditions.
- People will need to continue working alongside machines to produce the growth in per capita GDP to which countries around the world aspire. Our productivity estimates assume that people displaced by automation will find other employment. The anticipated shift in the activities in the labor force is of a similar order of magnitude as the long-term shift away from agriculture and decreases in manufacturing share of employment in the United States, both of which were accompanied by the creation of new types of work not foreseen at the time.
- For business, the performance benefits of automation are relatively clear, but the issues are more complicated for policy-makers. They should embrace the opportunity for their economies to benefit from the productivity growth potential and put in place policies to encourage investment and market incentives to encourage continued progress and innovation. At the same time, they must evolve and innovate policies that help workers and institutions adapt to the impact on employment. This will likely include rethinking education and training, income support and safety nets, as well as transition support for those dislocated. Individuals in the workplace will need to engage more comprehensively with machines as part of their everyday activities, and acquire new skills that will be in demand in the new automation age.

AUTOMATION

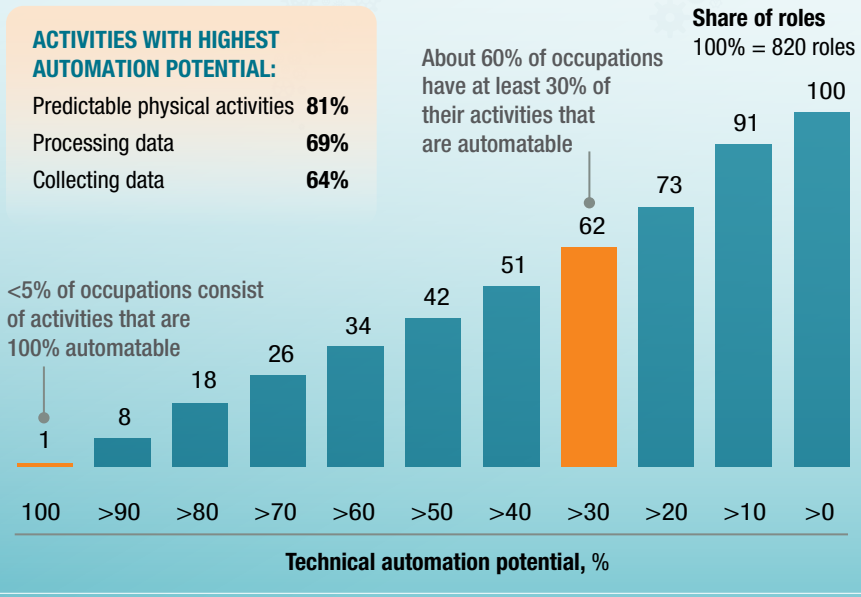
A global force that will transform economies and the workforce

Technical automation potential by adapting currently demonstrated technologies

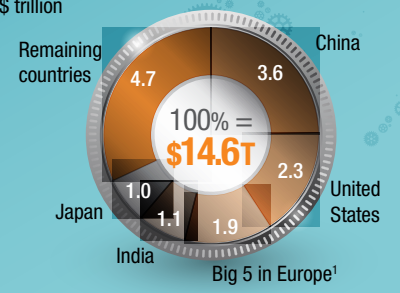
While few occupations are fully automatable, 60 percent of all occupations have at least 30 percent technically automatable activities

ACTIVITIES WITH HIGHEST AUTOMATION POTENTIAL:

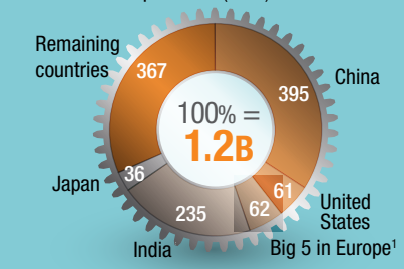
Predictable physical activities	**81%**
Processing data	**69%**
Collecting data	**64%**



Wages associated with technically automatable activities
$ trillion



Labor associated with technically automatable activities
Million full-time equivalents (FTEs)



[1] France, Germany, Italy, Spain, and the United Kingdom.

Five factors affecting pace and extent of adoption

1 TECHNICAL FEASIBILITY
Technology has to be invented, integrated, and adapted into solutions for specific case use

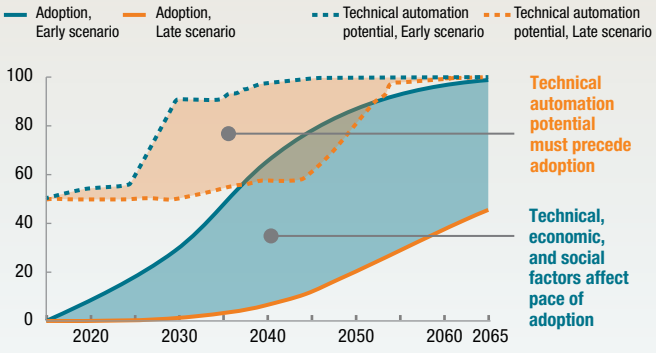
2 COST OF DEVELOPING AND DEPLOYING SOLUTIONS
Hardware and software costs

3 LABOR MARKET DYNAMICS
The supply, demand, and costs of human labor affect which activities will be automated

4 ECONOMIC BENEFITS
Include higher throughput and increased quality, alongside labor cost savings

5 REGULATORY AND SOCIAL ACCEPTANCE
Even when automation makes business sense, adoption can take time

Scenarios around time spent on current work activities, %

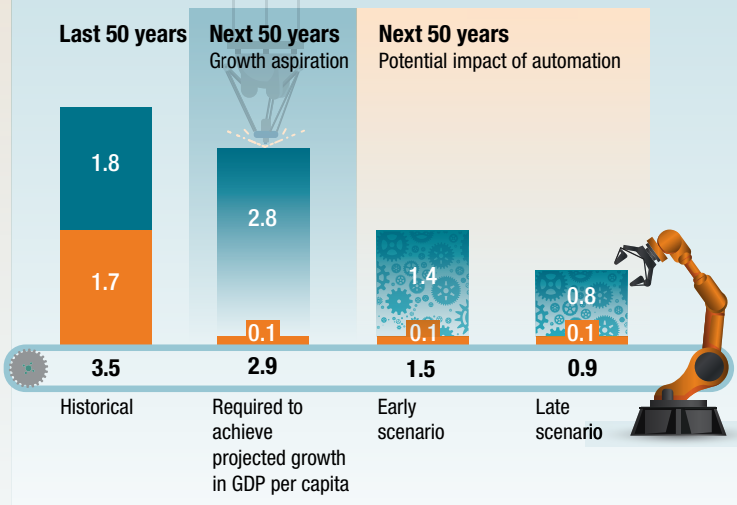


Automation will boost global productivity and raise GDP

G19 plus Nigeria

Productivity growth, %
Automation can help provide some of the productivity needed to achieve future economic growth

Employment growth, %
will slow drastically because of aging



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EXECUTIVE SUMMARY

Automation is not a new phenomenon, and questions about its promise and effects have long accompanied its advances. More than a half century ago, US President Lyndon B. Johnson established a national commission to examine the impact of technology on the economy and employment, declaring that automation did not have to destroy jobs but "can be the ally of our prosperity if we will just look ahead."[1] Many of the same questions have come to the fore again today, as a result of remarkable recent advances in technologies including robotics, artificial intelligence (AI), and machine learning. Automation now has the potential to change the daily work activities of everyone, from miners and landscape gardeners to commercial bankers, fashion designers, welders—and CEOs. But how quickly will these technologies become a reality in the workplace? And what will their impact be on employment and on productivity in the global economy?

Over the past two years, we have been conducting a research program on automation technologies and their potential effects. Some of our key findings include the following.

- We are living in a new automation age in which robots and computers can not only perform a range of routine physical work activities better and more cheaply than humans, but are also increasingly capable of accomplishing activities that include cognitive capabilities. These include making tacit judgments, sensing emotion, or even driving—activities that used to be considered too difficult to automate successfully.[2]

- The automation of activities can enable productivity growth and other benefits at both the level of individual process and businesses, as well as at the level of entire economies, where productivity acceleration is sorely needed, especially as the share of the working-age population declines in many countries. At a microeconomic level, businesses everywhere will have an opportunity to capture benefits and achieve competitive advantage from automation technologies, not just from labor cost reductions, but also from performance benefits such as increased throughput, higher quality, and decreased downtime. At a macroeconomic level, based on our scenario modeling, we estimate automation could raise productivity growth on a global basis by as much as 0.8 to 1.4 percent annually.

- Our approach to analyzing the potential impact of automation is through a focus on individual activities rather than entire occupations. Given currently demonstrated technologies, very few occupations—less than 5 percent—are candidates for full automation today, meaning that every activity constituting these occupations is automated. However, almost every occupation has partial automation potential, as a significant percentage of its activities could be automated. We estimate that about half of all the activities people are paid to do in the world's workforce could potentially be automated by adapting currently demonstrated technologies.

---

1 President Johnson signed the bill creating the National Commission on Technology, Automation, and Economic Progress, on August 19, 1964. The report was published in 1966. *Technology and the American economy: Report of the National Commission on Technology, Automation and Economic Progress*, US Department of Health, Education and Welfare, February 1966. In December 2016, the White House released a new report on the same subject, *Artificial intelligence, automation, and the economy*.

2 In this report we focus on the implications of automation technologies rather than on the technologies themselves. For a more detailed discussion of machine learning and deep learning technologies see the corresponding chapter in *The age of analytics: Competing in a data-driven world*, McKinsey Global Institute, December 2016.

- The pace and extent of automation, and thus its impact on workers, will vary across different activities, occupations, and wage and skill levels. Many workers will continue to work alongside machines as various activities are automated. Activities that are likely to be automated earlier include predictable physical activities, especially prevalent in manufacturing and retail trade, as well as collecting and processing data, which are activities that exist across the entire spectrum of sectors, skills and wages. Some forms of automation will be skill-biased, tending to raise the productivity of high-skill workers even as they reduce the demand for lower-skill and routine-intensive occupations, such as filing clerks or assembly-line workers.[3] Other automation has disproportionately affected middle-skill workers.[4] As technology development makes the activities of both low-skill and high-skill workers more susceptible to automation, these polarization effects could be reduced.

- Automation will have wide-ranging effects, across geographies and sectors. Although automation is a global phenomenon, four economies—China, India, Japan, and the United States—account for just over half of the total wages and almost two-thirds the number of employees associated with activities that are technically automatable by adapting currently demonstrated technologies. Within countries, automation potential will be affected by their sector mix, and the mix of activities within sectors. For example, industries such as manufacturing and agriculture include predictable physical activities that have a high technical potential to be automated, but lower wage rates in some developing countries could constrain adoption.

- Automation will not happen overnight, and five key factors will influence the pace and extent of its adoption. First is technical feasibility, since the technology has to be invented, integrated and adapted into solutions that automate specific activities. Second is the cost of developing and deploying solutions, which affects the business case for adoption. Third are labor market dynamics, including the supply, demand, and costs of human labor as an alternative to automation. Fourth are economic benefits, which could include higher throughput and increased quality, as well as labor cost savings. Finally, regulatory and social acceptance can affect the rate of adoption even when deployment makes business sense. Taking all of these factors into account, we estimate it will take decades for automation's effect on current work activities to play out fully. While the effects of automation might be slow at a macro level within entire sectors or economies, they could be quite fast at a micro level, for an individual worker whose activities are automated, or a company whose industry is disrupted by competitors using automation.

- While much of the current debate about automation has focused on the potential for mass unemployment, predicated on a surplus of human labor, the world's economy will actually need every erg of human labor working, in addition to the robots, to overcome demographic aging trends in both developed and developing economies. In other words, a surplus of human labor is much less likely to occur than a deficit of human labor, unless automation is deployed widely. However, the nature of work will change. As processes are transformed by the automation of individual activities, people will perform activities that are complementary to the work that machines do (and vice versa). These shifts will change the organization of companies, the structure and bases of competition of industries, and business models.

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[3] For a discussion of skill-biased and unskill-biased technical change see David H. Autor, Frank Levy, and Richard J. Murnane, "The skill content of recent technological change: An empirical explanation," *Quarterly Journal of Economics*, November 2003, and Daron Acemoglu and David H. Autor, "Skills, tasks, and technologies: Implications for employment and earnings," in *Handbook of Labor Economics*, volume 4B, David Card and Orley Ashenfelter, eds., Elsevier, 2011.

[4] David H. Autor, "Why are there still so many jobs? The history and future of workplace automation," *Journal of Economic Perspectives*, volume 29, number 3, 2015.

- For business, the performance benefits of automation are relatively clear, but the issues are more complicated for policy makers. They should embrace the opportunity for their economies to benefit from the productivity growth potential and put in place policies to encourage investment and market incentives to encourage continued progress and innovation. At the same time, they must evolve and innovate policies that help workers and institutions adapt to the impact on employment. This will likely include rethinking education and training, income support, and safety nets, as well as transition support for those dislocated. Individuals in the workplace will need to engage more comprehensively with machines as part of their everyday activities, and acquire new skills that will be in demand in the new automation age.

The scale of shifts in the labor force over many decades that automation technologies can unleash is of a similar order of magnitude to the long-term technology-enabled shifts in the developed countries' workforces away from agriculture in the 20th century. Those shifts did not result in long-term mass unemployment because they were accompanied by the creation of new types of work not foreseen at the time. We cannot definitively say whether historical precedent will be upheld this time. But our analysis shows that humans will still be needed in the workforce: the total productivity gains we estimate will come about only if people work alongside machines.

GAUGING AUTOMATION POTENTIAL IN THE GLOBAL WORKPLACE TODAY

The Czech writer Karel Capek coined the word "robot" almost a century ago, in a 1920 play about factory androids that each do the work of two-and-a-half humans at a fraction of the cost.[5] Science fiction has since become business fact. Robots are commonplace in manufacturing, and algorithms are playing an ever-larger role in companies from UPS to Amazon.[6] With recent developments in robotics, artificial intelligence, and machine learning, technologies not only do things that we thought only humans could do, but also can increasingly do them at superhuman levels of performance. Some robots that are far more flexible—and a fraction of the cost—of those used in manufacturing environments today can be "trained" by frontline staff to perform tasks that were previously thought to be too difficult for machines, and are even starting to take over service activities, from cooking hamburgers to dispensing drugs in hospital pharmacies. Artificial intelligence is also making major strides: in one recent test, computers were able to read lips with 95 percent accuracy, outperforming professional human lip readers who tested at 52 percent accuracy.[7]

We used the state of technology in respect to 18 performance capabilities to estimate the technical automation potential of more than 2,000 work activities from more than 800 occupations across the US economy, and then broadened our analysis across the global economy (see Box E1, "How we established the technical automation potential of the global economy").

[5] The word "robot" comes from the Slavic word for work, "robota." Karel Capek, *R.U.R. (Rossum's Universal Robots)*, 1920. The play is available at www.gutenberg.org.

[6] Steven Rosenbush and Laura Stevens, "At UPS, the algorithm is the driver," *Wall Street Journal*, February 16, 2015. Amazon employees can pick and pack three times as many products per hour with the help of robots. Eugene Kim, "Amazon is now using a whole lot more of the robots from the company it bought for $775 million," *Business Insider*, October 22, 2015; Kim Bhasin and Patrick Clark, "How Amazon triggered a robot arms race," *Bloomberg*, June 29, 2016.

[7] Hal Hodson, "Google's DeepMind AI can lip-read TV shows better than a pro," *New Scientist*, November 21, 2016.

Box E1. How we established the technical automation potential of the global economy

To assess the technical automation potential of the global economy, we used a disaggregation of occupations into constituent activities that people are paid to do in the global workplace. Each of these activities requires some combination of 18 performance capabilities, which we list in Exhibit E1. They are in five groups: sensory perception, cognitive capabilities, natural language processing, social and emotional capabilities, and physical capabilities.

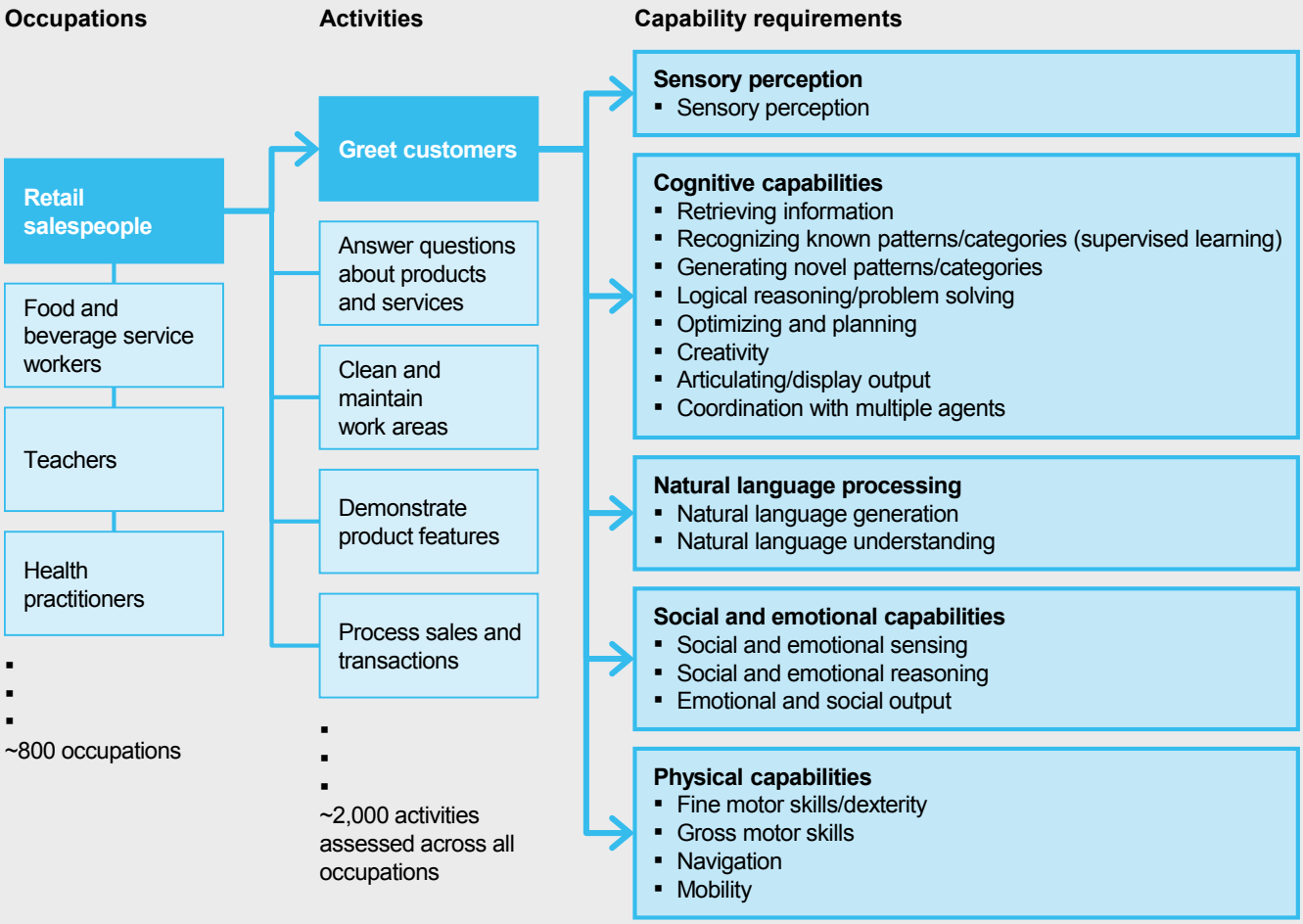
We estimated the level of performance for each of these capabilities that is required to perform each work activity successfully, based on the way humans currently perform activities—that is, whether the capability is required at all, and if so, whether the required level of performance was at roughly a median human level, below median human level, or at a high human level of performance (for example, top 25th percentile). We then assessed the performance of existing technologies today based on the same criteria.

This analysis enabled us to estimate the technical automation potential of more than 2,000 work activities in more than 800 occupations across the economy, based on data from the US Department of Labor. By estimating the amount of time spent on each of these work activities, we were able to estimate the automation potential of occupations in sectors across the economy, comparing them with hourly wage levels. Drawing on industry experts, we also developed scenarios for how rapidly the performance of automation technologies could improve in each of these capabilities.

The analysis we conducted for the United States provided us with a template for estimating the automation potential and creating adoption timing scenarios for 45 other economies representing about 80 percent of the global workforce. For details of our methodology, see the technical appendix.

Exhibit E1

To assess the technical potential of automation, we structure our analysis around 2,000 distinct work activities



SOURCE: McKinsey Global Institute analysis

Only a small percentage of occupations can be fully automated by adapting current technologies, but some work activities of almost all occupations could be automated

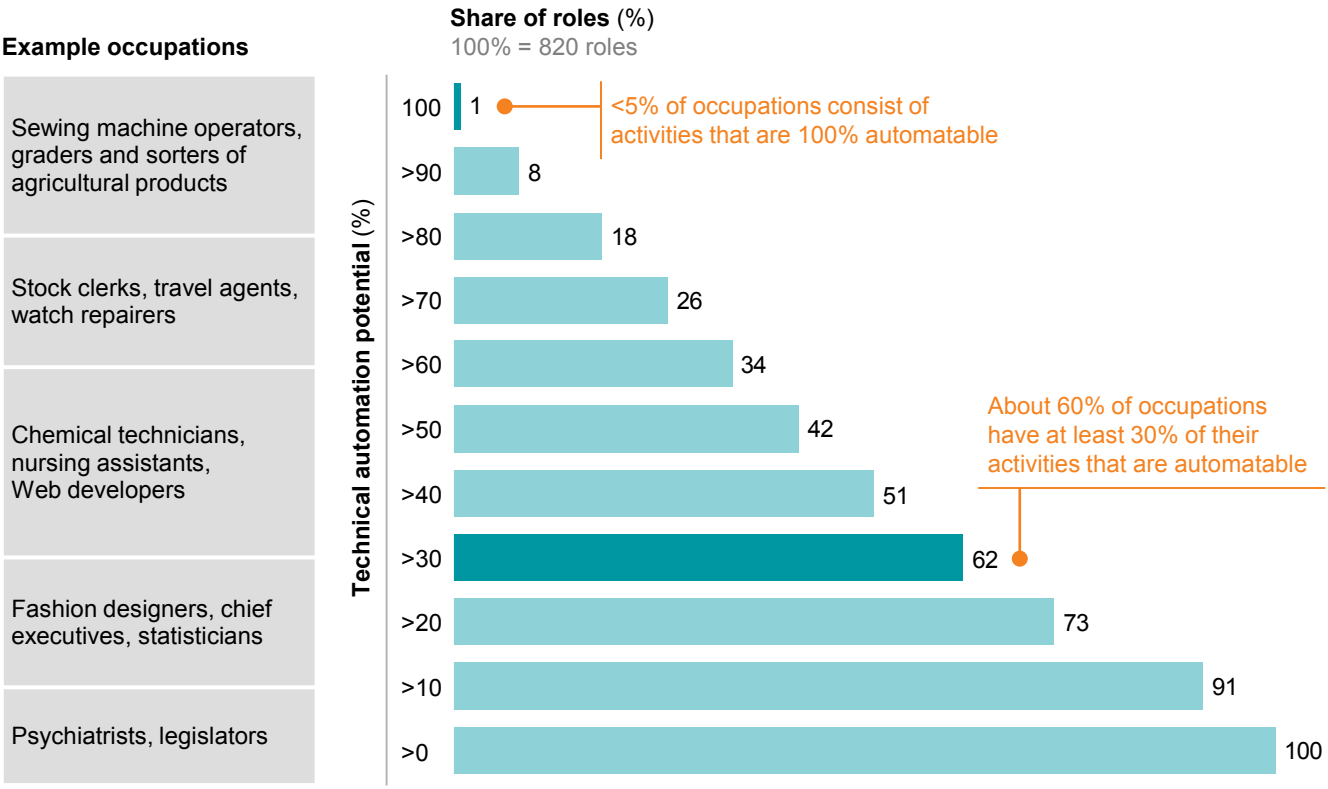
Unlike some other studies, the core of our analysis focuses on work activities rather than whole occupations. We consider work activities a more relevant and useful measure since occupations are made up of a range of activities with different potential for automation.[8] For example, a retail salesperson will spend some time interacting with customers, stocking shelves, or ringing up sales. Each of these activities is distinct and requires different capabilities to perform successfully.

Overall, we estimate that 50 percent of the activities that people are paid to do in the global economy have the potential to be automated by adapting currently demonstrated technology. While less than 5 percent of occupations can be fully automated, about 60 percent have at least 30 percent of activities that can technically be automated (Exhibit E2). While certain categories of activity, such as processing or collecting data, or performing physical activities and operating machinery in a predictable environment, have a high technical potential for automation, the susceptibility is significantly lower for other activities including interfacing with stakeholders, applying expertise to decision making, planning, and creative tasks, or managing and developing people (Exhibit E3).

Exhibit E2

While few occupations are fully automatable, 60 percent of all occupations have at least 30 percent technically automatable activities

Automation potential based on demonstrated technology of occupation titles in the United States (cumulative)[1]



1 We define automation potential according to the work activities that can be automated by adapting currently demonstrated technology.

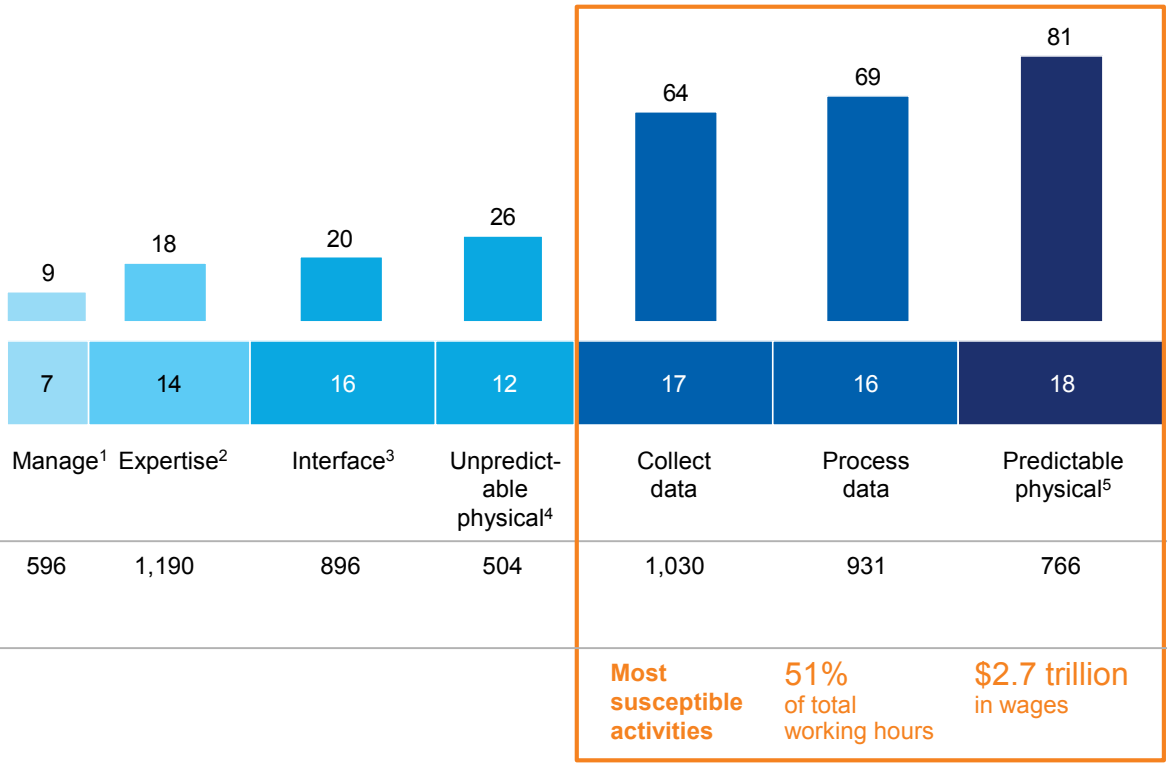
SOURCE: US Bureau of Labor Statistics; McKinsey Global Institute analysis

[8] Most recent studies estimating the impact of automation in the workplace focus on occupations. See Carl Benedikt Frey and Michael A. Osborne, *The future of employment: How susceptible are jobs to computerisation?* Oxford Martin School, September 17, 2013; *The future of jobs: Employment, skills, and workforce strategy for the fourth Industrial Revolution*, World Economic Forum, January 2016.

Exhibit E3

Three categories of work activities have significantly higher technical automation potential

Time spent on activities that can be automated by adapting currently demonstrated technology
%



	Manage[1]	Expertise[2]	Interface[3]	Unpredict-able physical[4]	Collect data	Process data	Predictable physical[5]
Time spent in all US occupations %	7	14	16	12	17	16	18
Total wages in US, 2014 $ billion	596	1,190	896	504	1,030	931	766

1 Managing and developing people.
2 Applying expertise to decision making, planning, and creative tasks.
3 Interfacing with stakeholders.
4 Performing physical activities and operating machinery in unpredictable environments.
5 Performing physical activities and operating machinery in predictable environments.
NOTE: Numbers may not sum due to rounding.

SOURCE: US Bureau of Labor Statistics; McKinsey Global Institute analysis

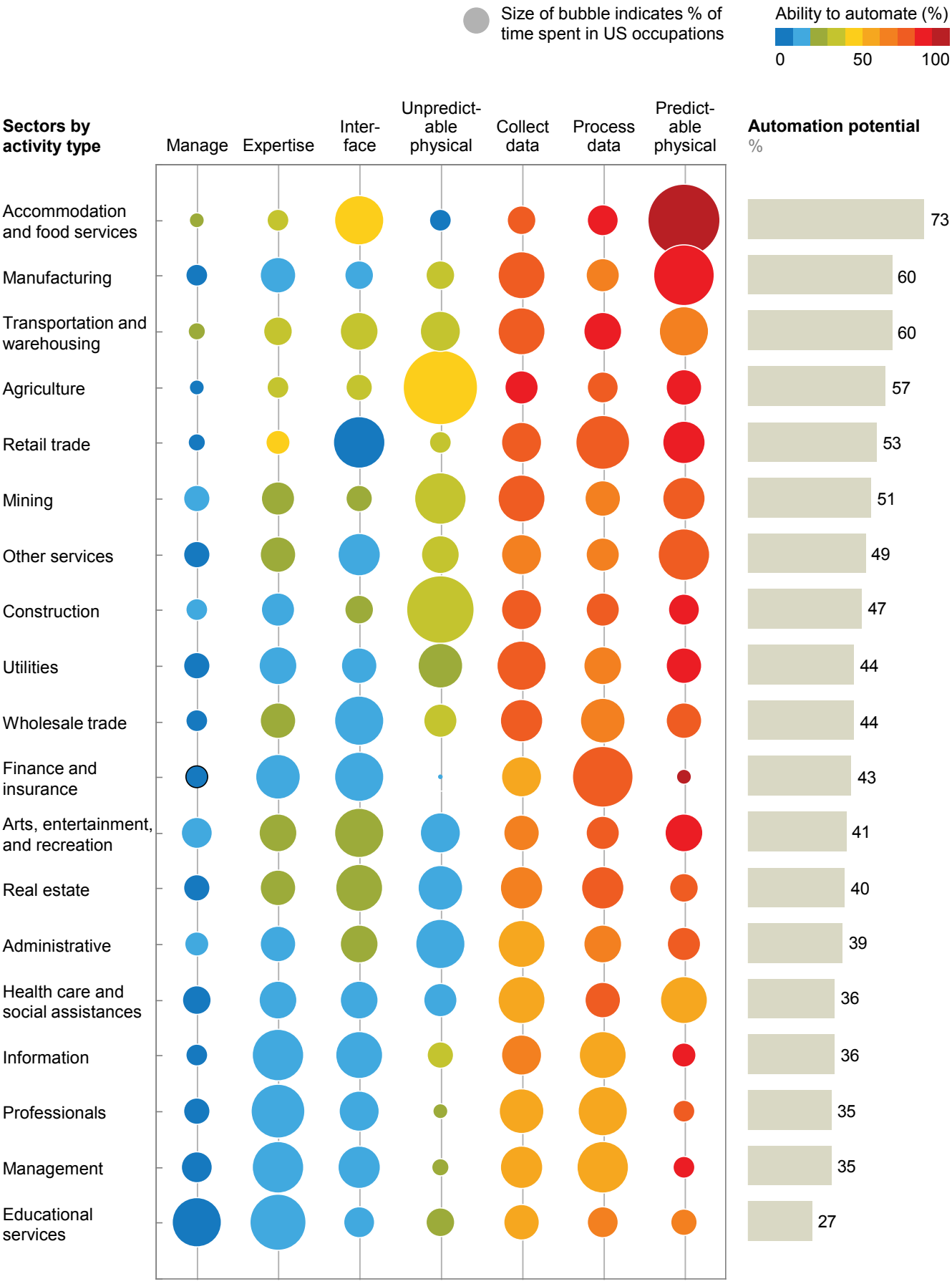
The degree of automation potential varies considerably among sectors and countries

A significant degree of variation among sectors of the economy, and among the occupations within those sectors, emerges from this analysis. For example, almost one-fifth of the time spent in US workplaces involves predictable physical activity and is prevalent in such sectors as manufacturing and retail trade. Accordingly, these sectors have a relatively high technical potential for automation using today's technology. Exhibit E4 shows a range of sectors in the US economy broken down into different categories of work activity.[9]

[9] An interactive mapping of the automation potential of multiple sectors of the economy is available online at **http://public.tableau.com/profile/mckinsey.analytics#!/**

Exhibit E4

Technical potential for automation across sectors varies depending on mix of activity types



SOURCE: US Bureau of Labor Statistics; McKinsey Global Institute analysis

Within sectors, too, there is considerable variation. In manufacturing, for example, occupations that have a large proportion of physical activities in predictable environments such as factory welders, cutters, and solderers have a technical automation potential above 90 percent based on adapting currently developed technologies, whereas for customer service representatives that susceptibility is less than 30 percent.

While wage and skill levels are negatively correlated with technical automation potential (on average, occupations with higher wages and skill requirements have lower automation potential, reflecting some skill bias), a large amount of variation underlies the averages. Essentially all occupations, whether high skill or low skill, have some technical automation potential, including CEOs; we estimate about 25 percent of their work could potentially be automated, primarily such tasks as analyzing reports and data to inform decisions, reviewing status reports, preparing staff assignments, and so on.

At a global level, technically automatable activities touch the equivalent of 1.2 billion employees and $14.6 trillion in wages (Exhibit E5). Four economies—China, India, Japan, and the United States—account for just over half of these total wages and employees; China and India together account for the largest technically automatable employment potential—more than 700 million full-time equivalents between them—because of the relative size of their labor forces. The potential is also large in Europe: according to our analysis, 62 million full-time employee equivalents and more than $1.9 trillion in wages are associated with technically automatable activities in the five largest economies—France, Germany, Italy, Spain, and the United Kingdom.

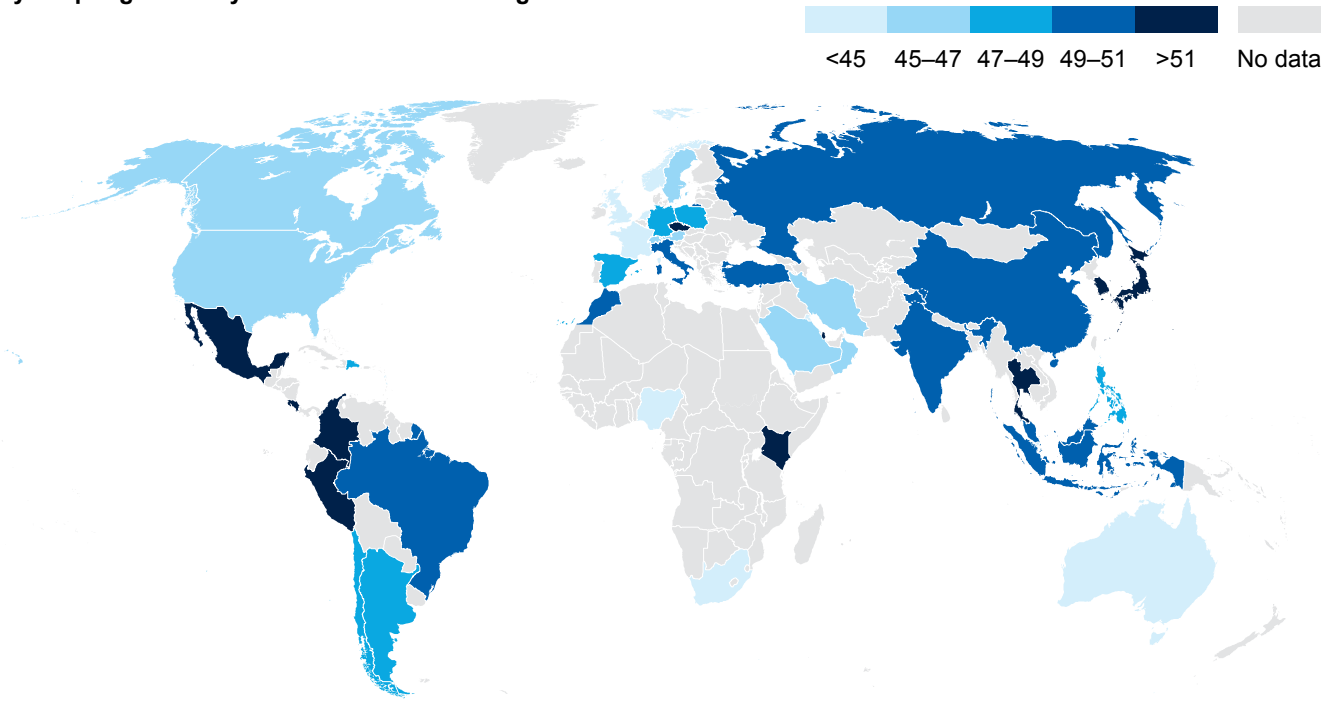
Our analysis of the technical automation potential of the global economy shows that there is a range among countries of about 15 percentage points. Two factors explain this range. The first is the sectoral makeup of each economy, that is, the proportion of a national economy that is in sectors such as manufacturing or accommodation and food services, both of which have relatively high automation potential, compared with the proportion in sectors with lower automation potential such as education. The second factor is the occupational makeup of sectors in different countries, in other words, the extent to which workers in these sectors are engaged in job titles with high automation potential, such as manufacturing production, and those in job titles with lower automation potential such as management and administration. A detailed look at all 46 countries we have examined is available online.[10]

[10] The data visualization can be found on the McKinsey Global Institute public site at tableau.com: **http://public.tableau.com/profile/mckinsey.analytics#!/**

Exhibit E5

The technical automation potential of the global economy is significant, although there is some variation among countries

Employee weighted overall % of activities that can be automated by adapting currently demonstrated technologies[1]

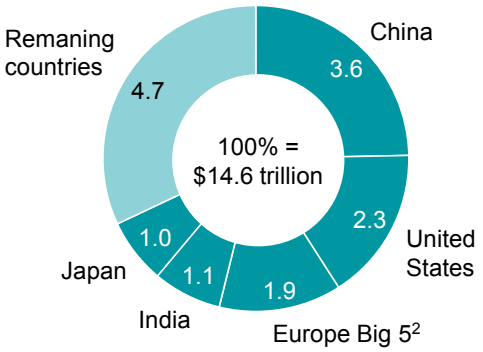


Technical automation potential is concentrated in countries with the largest populations and/or high wages

Potential impact due to automation, adapting currently demonstrated technology (46 countries)

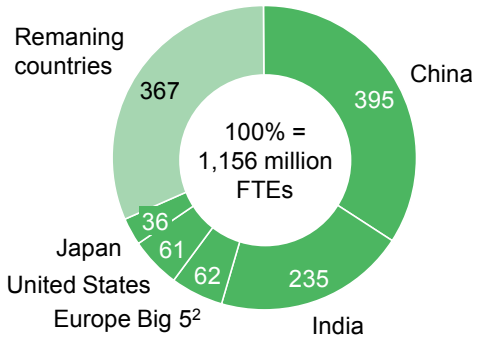
Wages associated with technically automatable activities

$ trillion



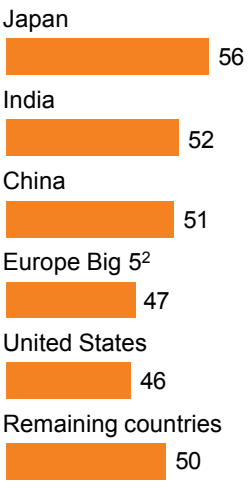
Labor associated with technically automatable activities

Million FTE



Automation potential

%



1 Pakistan, Bangladesh, Vietnam, and Iran are largest countries by population not included.
2 France, Germany, Italy, Spain, and the United Kingdom.
NOTE: Numbers may not sum due to rounding.

SOURCE: Oxford Economic Forecasts; Emsi database; US Bureau of Labor Statistics; McKinsey Global Institute analysis

FACTORS AFFECTING PACE AND EXTENT OF AUTOMATION

While the technology is advancing, the journey from technical automation potential to full adoption is nonetheless likely to take decades. The timing is affected by five sets of factors:

- **Technical feasibility.** Technology has to be invented, integrated and adapted into solutions that automate specific activities. Deployment in the workplace can begin only when machines have reached the required level of performance in the capabilities required to carry out particular activities. While machines can already match or outperform humans on some of the 18 capabilities in our framework, including information retrieval, gross motor skills, and optimization and planning, many other capabilities require more technological development. In particular, advancements in natural language understanding could unlock significantly more technical automation potential. Emotional and social reasoning capabilities will also need to become more sophisticated for many work activities. For typical work activities, multiple capabilities, such as sensory perception and mobility, will be needed simultaneously, and thus solutions that integrate specific capabilities in context must be engineered.

- **Cost of developing and deploying solutions.** The cost of automation affects the business case for adoption. Developing and engineering automation technologies takes capital. Hardware solutions range from standard computers to highly designed, application-specific hardware such as robots with arms and other moving parts requiring dexterity. Cameras and sensors are needed for any activity requiring sensory perception capabilities, while mobility requires wheels or other hardware that enable machines to move. Such attributes increase costs relative to a general-purpose hardware platform. Even "virtual" solutions that are based on software require real investments in engineering to create solutions. For deployment, hardware requires significant capital spending, and thus automation that requires it has high initial costs compared to wages. Software solutions, by comparison, tend to have a minimal marginal cost, which usually makes them less expensive than wages and thus they tend to be adopted earlier. Over time, both hardware and software costs decline, making solutions competitive with human labor for an increasing number of activities.

- **Labor market dynamics.** The quality (for instance, skills), quantity, as well as supply, demand, and costs of human labor as an alternative affect which activities will be automated. For example, restaurant cooking has high automation potential, more than 75 percent, based on currently demonstrated technologies, but the decision to deploy the technology will need to take into account the wage costs of cooks, who earn $11 per hour on average in the United States, and the abundance of people willing to working as cooks at that wage. Labor market dynamics also differ by geography, not only in terms of how different and evolving demographics affect the base supply of labor, but also different wage rates. Manufacturing automation is more likely to be adopted sooner in countries with high manufacturing wages, such as North America and Western Europe, than in developing countries with lower wages. Furthermore, the effects of automation can interact with labor market skills and supply. For example, if middle-income workers such as clerks and factory workers are displaced by the automation of data collection and processing and predictable physical activities, they could find themselves moving into lower paid occupations, increasing supply, and potentially putting downward pressure on wages. Conversely, they might take time to retrain into other high-skill positions, delaying their re-entry into the labor force, and temporarily reducing labor supply.

- **Economic benefits.** In addition to labor cost savings, a business case for automation could include performance gains such as increased profit, increased throughput and productivity, improved safety, and higher quality, which sometimes exceed the benefits

of labor substitution (see Box E2, "Automation technologies could provide significant performance benefits for companies beyond labor substitution"). For example, the benefits of increased production and lower overall maintenance costs by automating the control room of an oil and gas production facility dwarf those associated with reduced labor costs in the control room. Automated driving of cars and trucks could not only reduce the labor costs associated with drivers; it could also potentially improve safety (the vast majority of accidents are the result of driver errors) and fuel efficiency.

Box E2. Automation technologies could provide significant performance benefits for companies beyond labor substitution

The deployment of automation technologies could bring a range of performance benefits for companies. These benefits are varied, depending on the individual use case, and potentially very substantial—in some cases, considerably larger than cost reductions associated with labor substitution. They include, but are not limited to, greater throughput, higher quality, improved safety, reduced variability, a reduction of waste, and higher customer satisfaction.

We developed several hypothetical case studies to gain a better understanding of the potential for automation in different settings and sought to quantify the economic impact of realizing this vision. The case studies are of a hospital emergency department, aircraft maintenance, oil and gas operations, a grocery store, and mortgage brokering. The results—while forward-looking—are nonetheless striking. The value of the potential benefits of automation, calculated as a percentage of operating costs, ranges from between 10-15 percent for a hospital emergency department and a grocery store, to 25 percent for aircraft maintenance, and more than 90 percent for mortgage origination.

We also see automation being deployed today that is already generating real value. For example, Rio Tinto has deployed automated haul trucks and drilling machines at its mines in Pilbara, Australia, and says it is seeing 10–20 percent increases in utilization there as a result.[1] Google has applied artificial intelligence from its DeepMind machine learning to its own data centers, cutting the amount of energy they use by 40 percent.[2] In financial services, automation in the form of "straight-through processing," where transaction workflows are digitized end-to-end, can increase the scalability of transaction throughput by 80 percent, while concurrently reducing errors by half.[3] Safety is another area that could benefit from increased automation. For example, of the approximately 35,000 road death in the United States annually, about 94 percent are the result of human error or choice.[4]

The relative cost of automation can be modest compared with the value it can create. The types and sizes of investment needed to automate will differ by industry and sector. For example, industries with high capital intensity that require substantial hardware solutions to automate and are subject to heavy safety regulation will likely see longer lags between the time of investment and the benefits than sectors where automation will be mostly software-based and less capital-intensive. For the former, this will mean a longer journey to breakeven on automation investment. However, our analysis suggests that the business case can be compelling regardless of the degree of capital intensity.

1 *Productivity improvements in a changing world*, presentation by Michael Gollschewski, managing director Pilbara Mines, Rio Tinto, July 13, 2015.

2 Rich Evans and Jim Gao, *DeepMind AI reduces energy used for cooling Google data centers by 40%*, Google, blog post, July 20, 2016.

3 João Bueno, Yran Bartolumeu Dias, Alexandre Sawaya, Jorge Valadas. "End-to-end digitization for securities services," *McKinsey on Payments*, September 2014.

4 "Barack Obama: Self-driving, yes, but also safe," *Pittsburgh Post-Gazette*, September 19, 2016.

- **Regulatory and social acceptance.** Even when deploying automation makes business sense, the rate of adoption can be affected by contextual factors such as regulatory approval and the reaction of users. There are multiple reasons that technology adoption does not happen overnight. The shift of capital investment into these new technologies takes time (in aggregate), as does changing organizational processes and practices to adapt to new technologies. Reconfiguring supply chains and ecosystems can be laborious, and regulations sometimes need to change. Government policy can slow adoption, and different businesses adopt technologies at different rates. Changing the activities that workers do also requires dedicated effort, even if they are not actively resisting. And especially in the case of automation, individuals may feel uncomfortable about a new world where machines replace human interaction in some intimate life settings, such as a hospital, or in places where machines are expected to make life-and-death decisions, such as when driving.

Automation adoption will take decades, across a wide range of possible scenarios

To analyze a range of potential scenarios for the pace at which automation will affect activities across the global economy, we constructed a model that simplifies the effects of these five factors into four timing stages: capability development, solution development, economic feasibility, and final adoption. The S-curve in Exhibit E6 indicates the potential time range that emerges from our scenario analyses, with the dark blue line representing an "earliest adoption" scenario and the light blue line a "latest adoption" scenario, aggregating across all of the activities that account for about 80 percent of the world's workforce. For example, we estimate that adapting currently demonstrated technology has the technical potential to automate roughly 50 percent of the world's current work activities. While the date at which this could happen could be around 2055, assuming all the factors are in place for successful adoption by then, we modeled possible scenarios where that level of adoption occurs up to almost 20 years earlier or later.

Among the first sectors likely to feel the impact of automation will be those that involve types of activities we categorize as having the highest automation potential today based on currently demonstrated technology. From a geographical perspective, advanced economies are also likely to deploy automation ahead of many emerging economies, largely because of higher wage levels, which make a stronger business case for deployment.

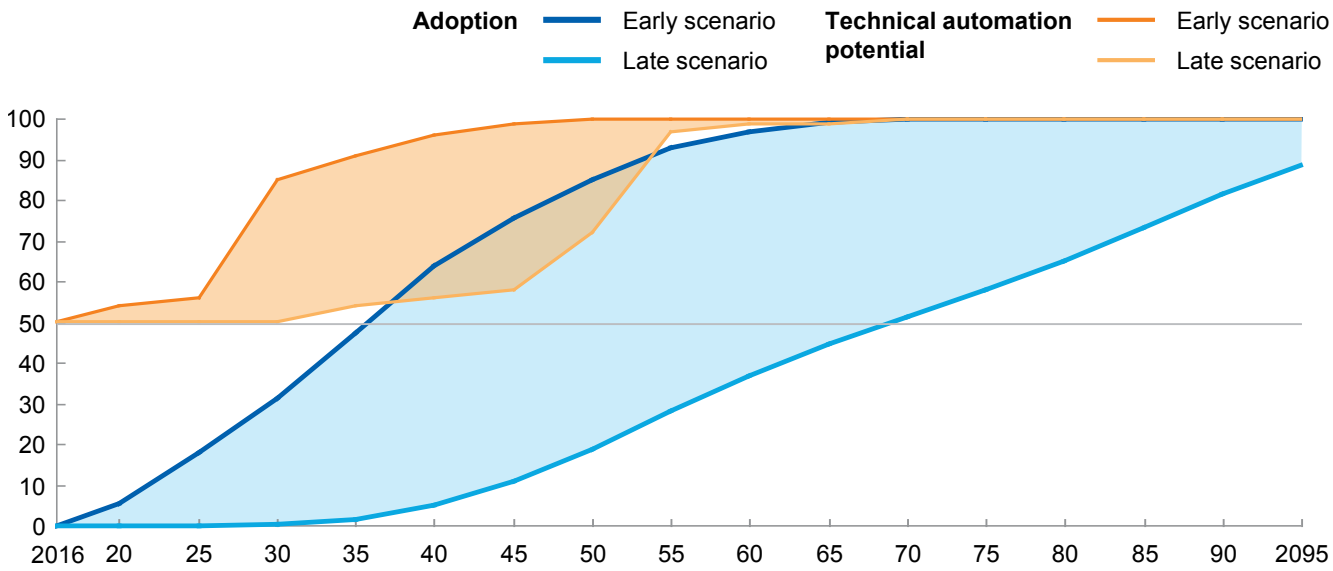
This magnitude of shifts in work activities over multiple decades is not unprecedented. In the United States, for example, the share of farm employment fell from 40 percent in 1900 to 2 percent in 2000, while the share of manufacturing employment fell from approximately 25 percent in 1950 to less than 10 percent in 2010 (Exhibit E7).[11] In both cases, new activities and jobs were created that offset those that disappeared, although it was not possible to predict what those new activities and jobs would be while these shifts were occurring.

[11] Stanley Lebergott, "Labor force and employment 1800–1960," in *Output, employment, and productivity in the United States after 1800*, Dorothy S. Brady, ed., NBER, 1966; World Bank data; Mack Ott, "The growing share of services in the US economy—degeneration or evolution?" *Federal Reserve Bank of St. Louis Review*, June/July 1987.

Exhibit E6

Automation will be a global force, but adoption will take decades and there is significant uncertainty on timing

Time spent on current work activities[1]
%



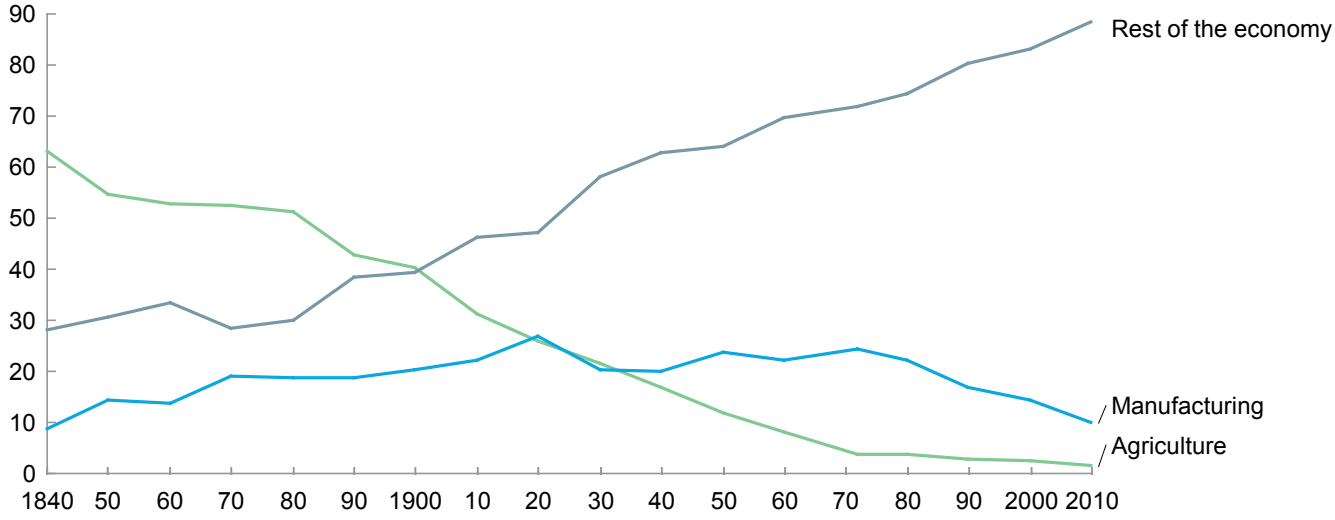
1 Forty-six countries used in this calculation, representing about 80% of global labor force.

SOURCE: McKinsey Global Institute analysis

Exhibit E7

Employment in agriculture has fallen from 40 percent in 1900 to less than 2 percent today

Distribution of labor share by sector in the United States, 1840–2010
%



SOURCE: Stanley Lebergott, "Labor force and employment 1800–1960," in *Output, employment, and productivity in the United States after 1800*, Dorothy S. Brady, ed., NBER, 1966; World Data Bank, World Bank Group; FRED: Economic Research, Federal Reserve Bank of St. Louis; Mack Ott, "The growing share of services in the US economy—degeneration or evolution?" *Federal Reserve Bank of St. Louis Review*, June/July 1987; McKinsey Global Institute analysis

Modeling scenarios for the pace and extent of automation adoption

Capability development is the first stage that we modeled for the timing of automation adoption. Deployment in the workplace can begin only when machines have reached the required level of performance in the capabilities required to carry out particular activities.

Once the technical capabilities have been developed, they must be integrated into solutions that can execute specific activities in context, that is, to create commercially available systems. Our analysis suggests that, on average, this solution development process can take between one and nine years.

The third stage we modeled for scenario timelines is when automation is economically feasible. For modeling purposes, we assume that adoption begins when the developed solution for any given activity is at or below the cost for human workers to perform that activity in a specific occupation and within a particular country.[12] While the performance benefits of automation sometimes exceed those related to labor cost savings, our conservative modeling assumes that decision-makers discount the benefits of initial labor cost savings by roughly the same amount as they believe the also uncertain non-labor cost-related benefits will be captured.

Adoption and deployment of automation, the fourth stage we modeled to develop scenarios, can also be a slow process. For our analysis, we looked at the historical adoption rates a wide range of 25 technologies, involving both hardware and software, as well as business and consumer technologies. The time between the commercial availability of these technologies and their eventual maximum level of adoption generally took at least nearly a decade and in some cases multiple decades, with the time range between eight and 28 years.[13]

EVEN AS IT CAUSES SHIFTS IN EMPLOYMENT, AUTOMATION CAN GIVE A STRONG BOOST TO PRODUCTIVITY AND GLOBAL GDP GROWTH

Automation will cause significant labor displacement and could exacerbate a growing skills and employment gap that already exists between high-skill and low-skill workers.[14] Our analysis of automation potential also suggests that many occupations could be partially automated before they are fully automated, which could have different implications for high- and low-skill workers.[15] Especially for low-skill workers, this process could depress wages unless demand grows. Viewed through a long-term perspective, however, as we described previously, large-scale historical structural shifts in the workplace where technology has caused job losses have, over time, been accompanied by the creation of a multitude of new jobs, activities, and types of work.[16] Furthermore, labor markets can be quite dynamic: almost five million people leave their jobs every month in the United States, of whom about

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12 By costs in this case, we mean wages plus benefits, calculated globally on a purchasing power parity basis.

13 Some of the technologies we modeled have not likely yet reached their eventual peak in adoption.

14 There has been a proliferation of books by competing schools of "techno-optimists" and "techno-pessimists." They notably include Erik Brynjolfsson and Andrew McAfee, *The second machine age: Work, progress, and prosperity in a time of brilliant technologies*, W. W. Norton & Company, 2014; Robert Gordon, *The rise and fall of American growth: The US standard of living since the Civil War*, Princeton University Press, 2016; and Martin Ford, *Rise of the robots: Technology and the threat of a jobless future*, Basic Books, 2015. Also Jason Furman, "Is this time different? The opportunities and challenges of artificial intelligence," remarks at AI Now: The Social and Economic Implications of Artificial Intelligence Technologies in the Near Term conference in New York, July 7, 2016.

15 For a discussion of the polarization of the labor market, see David H. Autor and David Dorn, "The growth of low-skill service jobs and the polarization of the US labor market," *American Economic Review*, volume 103, number 5, August 2013.

16 For example, a study conducted by McKinsey & Company's French office in 2011 showed that for every job that had been lost in France as the result of the advent of the internet in the previous 15 years, 2.4 new jobs had been created. *Impact d'internet sur l'économie française: Comment internet transforme notre pays (The internet's impact on the French economy: How the internet is transforming our country)*, McKinsey & Company, March 2011.

three million do so voluntarily. Most of these people are not unemployed for long periods as they move on to other jobs.[17]

That said, automation also represents a very substantial opportunity to support global economic growth. Our estimates suggest it has the potential to contribute meaningfully to the growth necessary to meet the per capita GDP aspirations of every country, at a time when changing demographics call those aspirations into question. Indeed, for this growth to take place, rather than having a massive labor surplus, everyone needs to keep working—with the robots working alongside them.

Automation can help close a GDP growth gap resulting from declining growth rates of working-age populations

GDP growth was brisk over the past half century, driven by the twin engines of employment growth and rising productivity, both contributing approximately the same amount. However, declining birthrates and the trend toward aging in many advanced and some emerging economies mean that peak employment will occur in most countries within 50 years.[18] The expected decline in the share of the working-age population will open an economic growth gap: roughly half of the sources of economic growth from the past half century (employment growth) will evaporate as populations age. Even at historical rates of productivity growth, economic growth could be nearly halved.

Automation could compensate for at least some of these demographic trends. We estimate the productivity injection it could give to the global economy as being between 0.8 and 1.4 percent of global GDP annually, assuming that human labor replaced by automation would rejoin the workforce and be as productive as it was in 2014. Considering the labor substitution effect alone, we calculate that, by 2065, automation could potentially add productivity growth in the largest economies in the world (G19 plus Nigeria) that is the equivalent of an additional 1.1 billion to 2.3 billion full-time workers (Exhibit E8).

The productivity growth enabled by automation can ensure continued prosperity in aging nations and provide an additional boost to fast-growing ones. Automation on its own will not be sufficient to achieve long-term economic growth aspirations across the world; for that, additional productivity-boosting measures will be needed, including reworking business processes or developing new products and services.

Potential impact of automation in three groups of countries

Automation could boost productivity and help close the economic growth gap in the 20 largest economies in the medium term, to 2030. We have divided these countries into three groups, each of which could use automation to further national economic growth objectives, depending on their demographic trends and growth aspirations. The three groups are:

- Advanced economies, including Australia, Canada, France, Germany, Italy, Japan, South Korea, the United Kingdom, and the United States. These economies typically face an aging workforce, with the decline in working-age population growth more immediate in some (Germany, Italy, and Japan) than in others. Automation can provide the productivity boost required to meet economic growth projections that they otherwise would struggle to attain without other significant productivity growth accelerators. These economies thus have a major interest in pursuing rapid automation adoption.

- Emerging economies with aging populations. This category includes Argentina, Brazil, China, and Russia, which face economic growth gaps as a result of projected declines in

[17] US Bureau of Labor Statistics job openings and labor turnover survey database.

[18] *Global growth: Can productivity save the day in an aging world?* McKinsey Global Institute, January 2015. Our estimate of employment growth's contribution to GDP growth in this report differs slightly from this earlier research, as we have assumed productivity measured in each country, rather than a global average.

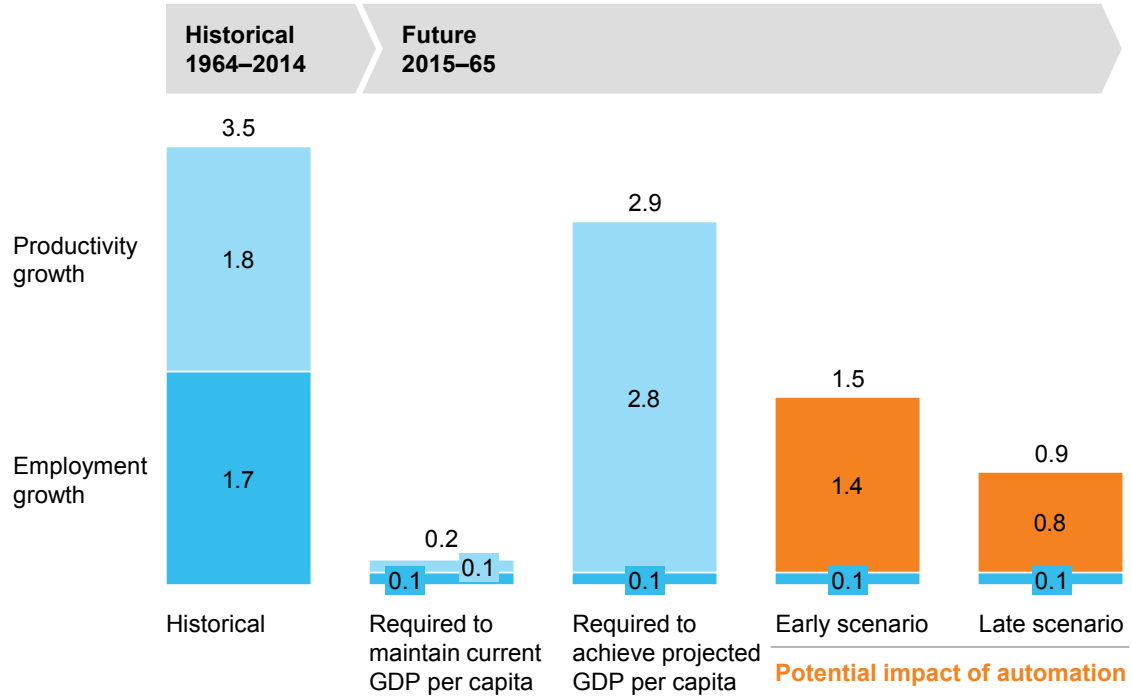
the growth of their working population.[19] For these economies, automation can provide the productivity injection needed just to maintain current GDP per capita. To achieve a faster growth trajectory that is more commensurate with their developmental aspirations, these countries would need to supplement automation with additional sources of productivity, such as process transformations, and would benefit from more rapid adoption of automation.

- Emerging economies with younger populations. These include India, Indonesia, Mexico, Nigeria, Saudi Arabia, South Africa, and Turkey.[20] The continued growth of the working-age population in these countries could support maintaining current GDP per capita. However, given their high growth aspirations, automation plus additional productivity-raising measures will be necessary to sustain their economic development.

Exhibit E8

Globally, automation could become a significant economic growth engine as employment growth wanes

GDP growth for G19 and Nigeria
Compound annual growth rate
%



	Historical	Required to maintain current GDP per capita	Required to achieve projected GDP per capita	Potential impact of automation
GDP per capita growth Compound annual growth rate %	2.1	0	2.5	0.5–1.1
Full-time equivalent gap[1] Billion		0.1	6.7	

1 Additional full-time equivalents (FTEs) needed to achieve growth target.
NOTE: Numbers may not sum due to rounding.

SOURCE: The Conference Board Total Economy database; United Nations Population Division; McKinsey Global Institute analysis

[19] The demographic trends are pronounced for China and Russia, while Argentina's future workforce gap is less certain.

[20] The populations of Saudi Arabia and Turkey are projected to grow strongly over the next 20 years, but slow thereafter.

The advances in automation and their potential impact on national economies could upend some prevailing models of development and challenge ideas about globalization. Countries experiencing population declines or stagnation will be able to maintain living standards even as the labor force wanes. Meanwhile, countries with high birthrates and a significant growth in the working-age population may have to worry more about generating new jobs in a new age of automation. Moreover, low-cost labor may lose some of its edge as an essential developmental tool for emerging economies, as automation drives down the cost of manufacturing globally.

HOW BUSINESS LEADERS, POLICY MAKERS, AND WORKERS CAN PREPARE FOR THE NEW AUTOMATION AGE

Business leaders, policy makers, and workers everywhere face considerable challenges in capturing the full potential of automation's beneficial effect on the economy, even as they navigate the major uncertainties about the social and employment repercussions.

Automation will give business leaders opportunities to improve their performance and enter new markets, but they will need to rework their processes and organizations

Automation of various activities can improve the performance of almost any business process.[21] Beyond enabling reduction in labor costs, automation can raise throughput, increase reliability, and improve quality, among other performance gains.

To assess where automation could be most profitably applied to improve performance, business leaders may want to conduct a thorough inventory of their organization's activities and create a heat map of where automation potential is high. Once they have identified business processes with activities that have high automation potential, these could be reimagined to take full advantage of automation technologies (rather than just mechanically attempting to automate individual activities in the current processes). They could then assess the benefits and feasibility of these automation-enabled process transformations.

Taking advantage of these transformations could lead to significant displacements in labor. Business leaders would be well served to consider how to best redeploy that labor, whether within their own organizations or elsewhere, both to improve their own performance and to act as good corporate citizens. Retraining and skill-raising programs will be important to support workers shifting to new roles and taking on new activities. It will also be critical for corporate leaders to ensure that the organizational elements of their companies are adapting to the advent of automation.

On a strategic level, automation could enable the emergence of massively scaled organizations, instantly able to propagate changes that come from headquarters. Technology will make measuring and monitoring easier, providing effective new tools for managers. However, greater scale means that errors could be more consequential, which in turn will require stronger quality controls.

Even as some corporations could be scaling up, automation and digital technologies more generally will enable small players, including individuals and small companies, to undertake project work that is now largely carried out within bigger firms. The growth of very small and very large companies could create a barbell-shaped economy, in which mid-sized companies lose out. In all sectors, automation could heighten competition, enabling firms to enter new areas outside their previous core businesses, and creating a growing divide between technological leaders and laggards in every sector.

[21] We explore several case studies of the potential transformations of business processes in Chapter 3.

For policy makers, an embrace of automation could be accompanied by measures to raise skills and promote job creation, and by rethinking incomes and social safety nets

Policy makers globally will have a strong incentive to encourage and enable rapid adoption of automation technologies in order to capture the full productivity boost necessary to support economic growth targets. At the same time, they will need to think through how to support the redeployment of potentially large numbers of displaced workers, since the full economic benefits of automation depend on workers continuing to work.[22]

Early adoption of automation could benefit from policy support, both in regard to the technology development, and for its deployment. That will require investment in developing the technologies themselves, and also in digitally enabled infrastructure to support automation.

Labor redeployment will be one of the most important societal challenges. Governments are often not particularly adept at anticipating the types of jobs that could be created, or new industries that will develop. However, they could initiate and foster dialogues about what work needs doing, and about the grand societal challenges that require more attention and effort.[23] Governments could also seek to encourage new forms of technology-enabled entrepreneurship, and intervene to help workers develop skills best suited for the automation age. For example, many economies are already facing a shortage of data scientists and business translators.[24] Governments working with the private sector could take steps to ensure that such gaps are filled, establishing new education and training possibilities.

One of the challenges of the new era will be to ensure that wages are high enough for the new types of employment that will be created, to prevent continuing erosion of the wage share of GDP, which has dropped sharply since the 1970s.[25] If automation does result in greater pressure on many workers' wages, some ideas such as earned income tax credits, universal basic income, conditional transfers, shorter workweeks, and adapted social safety nets could be considered and tested. As work evolves at higher rates of change among sectors, locations, activities, and skill requirements, many workers may need assistance in adjusting to the new age.

Workers will need to work more closely with technology, freeing up more time to focus on intrinsically human capabilities that machines cannot yet match

Men and women in the workplace will need to engage more comprehensively with machines as part of their everyday activities. Tighter integration with technology will free up time for human workers including managers to focus more fully on activities to which they bring skills that machines have yet to master. This could make work more complex, and harder to organize, with managers spending more time on coaching.[26]

As people make education and career choices, it will be important for them to be made aware of the factors driving automation in particular sectors, to help them identify the skills

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22 Jason Furman, "Is this time different? The opportunities and challenges of artificial intelligence," remarks at AI Now: The Social and Economic Implications of Artificial Intelligence Technologies in the Near Term conference in New York, July 7, 2016.

23 Tim O'Reilly, "Don't replace people. Augment them," Medium.com, July 17, 2016.

24 *The age of analytics: Competing in a data-driven world*, McKinsey Global Institute in collaboration with McKinsey Analytics, December 2016.

25 *Poorer than their parents? Flat or falling incomes in advanced economies*, McKinsey Global Institute, July 2016.

26 Daron Acemoglu and Pascual Restrepo, "The race between machines and humans: Implications for growth, factor shares and jobs," Vox, July 5, 2016.

that could be useful for them to acquire from a labor-market perspective, and what activities will be complements of activities that are likely to be automated.[27]

High-skill workers who work closely with technology will likely be in strong demand, and may be able to take advantage of new opportunities for independent work as the corporate landscape shifts and project work is outsourced by companies. Middle-skill workers whose activities have the highest technical potential for automation (predictable physical activities, collecting and analyzing data) can seek opportunities for retraining to prepare for shifts in their activities toward those that are complements of activities the machines will start to perform.

Low-skill workers working with technology will be able to achieve more in terms of output and productivity but may experience wage pressure given the potentially large supply of similarly low-skill workers.

Education systems will need to evolve for a changed workplace, with policy makers working with education providers to improve basic skills in the STEM fields of science, technology, engineering, and mathematics, and put a new emphasis on creativity, as well as on critical and systems thinking. For all, developing agility, resilience, and flexibility will be important at a time when everybody's job is likely to change to some degree.

Finally, automation will create an opportunity for those in work to make use of the innate human skills that machines have the hardest time replicating: logical thinking and problem solving, social and emotional capabilities, providing expertise, coaching and developing others, and creativity. For now, the world of work still expects men and women to undertake rote tasks that do not stretch these innate capabilities as far as they could. As machines take on ever more of the predictable activities of the workday, these skills will be at a premium. Automation could make us all more human.

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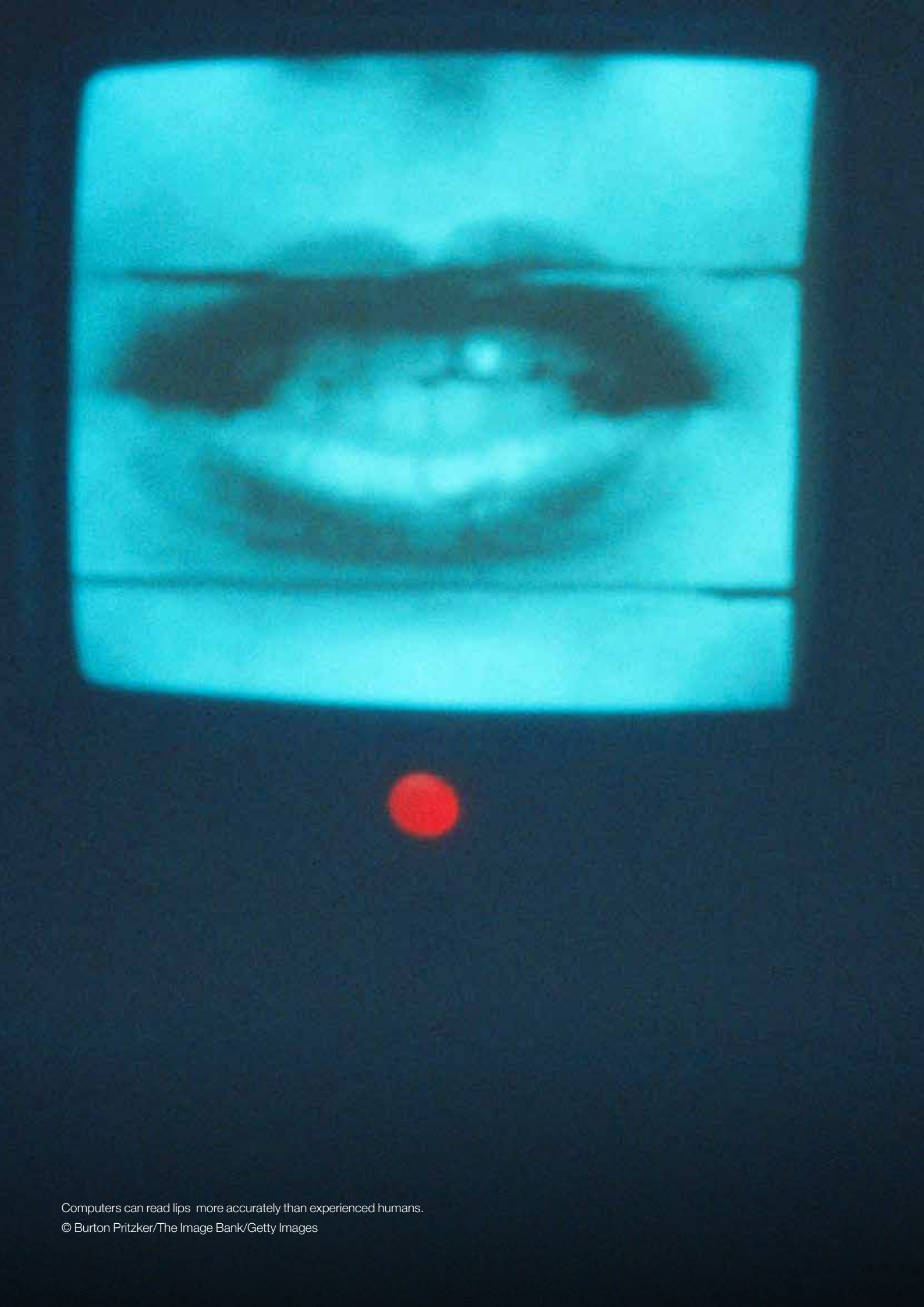
Automation will play an essential role in providing at least some of the productivity boost that the global economy needs over the next half century as growth in working-age populations declines. It will contribute meaningfully to GDP per capita growth, even if it will not on its own enable emerging economies to meet their fast-growth aspirations. Given the range of scenarios around the pace and extent of adoption of automation technologies, there are sure to be surprises. We will see large-scale shifts in workplace activities over the next century. These trends are already under way. Policy makers, business leaders, and workers themselves must not wait to take action: already today, there are measures that can be taken to prepare, so that the global economy can capture the opportunities offered by automation, even as it avoids the drawbacks.

[27] Erik Brynjolfsson and Andrew McAfee, *The second machine age: Work, progress, and prosperity in a time of brilliant technologies*, W. W. Norton & Company, 2014.

OVERVIEW OF SELECT RECENT STUDIES ON THE IMPACT OF AUTOMATION AND FUTURE OF WORK

Carl Benedikt Frey and Michael A. Osborne	Citibank with Frey and Osborne	OECD	World Economic Forum	McKinsey Global Institute
Date				
September 2013	January 2016	June 2016	January 2016	January 2017
Unit of analysis				
Jobs/occupations	Jobs/occupations	Tasks	Not applicable	Work activities
Scope				
US labor market	50+ countries and regions	21 OECD countries	15 major developed and emerging economies	46 countries representing about 80% of global labor force
Approach summary				
Analysis of 702 occupations (70 hand-labeled working with ML researchers, followed by a tailored Gaussian process classifier to estimate others and confirm hand-labels) to approximate the impact of future computerization on the US labor market	Extension of Frey-Osborne (2013), using World Bank data, to estimate impact of automation globally. Further analyses include examination of demographic changes, global value chain, etc.	Estimates of automatibility of tasks were developed based on matching of the automatibility indicators by Frey-Osborne and the PIAAC data occupational codes, followed by a two-step, tailored regression analysis	Analysis of large-scale survey of major global employers, including 100 largest global employers in each of WEF main industry sectors, to estimate the expected level of changes in job families between 2015–20 and extrapolate number of jobs gained/lost	Disaggregation of occupations into 2,000 constituent activities and rating each against human performance in 18 capabilities. Further analysis of time spent on each activity and hourly wage levels. Scenarios for development and adoption of automation technologies
Key relevant findings				
▪ About 47% of total US occupations are at high risk of automation perhaps over the next decade or two ▪ Wages and educational attainment show a strong negative relationship with probability of computerization	▪ Building on Frey and Osborne's original work, data from the World Bank suggests the risks are higher in many other countries; in the OECD, on average 57% of jobs are susceptible to automation. This number rises to 69% in India and 77% in China	▪ On average, 9% of jobs across the 21 OECD countries are automatable ▪ There are notable differences across OECD countries when it comes to automation (e.g., the share of automatable jobs is 6% in Korea vs. 12% in Austria)	▪ Automation and technological advancements could lead to a net employment impact of more than 5.1 million jobs lost to disruptive labor market changes between 2015–20, with a total loss of 7.1 million jobs—two-thirds of which are concentrated in the office and administrative job family—and a total gain of 2 million jobs in several smaller job families	▪ Almost half of work activities globally have the potential to be automated using current technology. <5% of occupations can be automated entirely; about 60% have at least 30% of automatable activities ▪ Technically automatable activities touch 1.2 billion workers and $14.6 trillion in wages. China, India, Japan, and the United States constitute over half ▪ Automation's boost to global productivity could be 0.8–1.4% annually over decades

SOURCE: Carl Benedikt Frey and Michael A. Osborne, *The future of employment: How susceptible are jobs to computerisation?,* Oxford Martin School, September 17, 2013; *Technology at Work v2.0: The future is not what it used to be*, Citibank, January 2016; *The future of jobs: Employment, skills, and workforce strategy for the fourth Industrial Revolution*, World Economic Forum, January 2016; Melanie Arntz, Terry Gregory, and Ulrich Zierahn, *The risk of automation for jobs in OECD countries: A comparative analysis*, OECD Social, Employment and Migration working paper number 189, OECD, May 2016; McKinsey Global Institute analysis. See also Holger Bonin, Terry Gregory, and Ulrich Zierahn, *Ubertragung der Studie von Frey/Osborne: (2013) auf Deutschland*, Forschungsbericht 455, Bundesministerium für Arbeit und Soziales, April 14, 2015; and Jeremy Bowles, *The computerisation of European jobs*, Bruegel, July 24, 2014.



Computers can read lips more accurately than experienced humans.

1. THE NEW FRONTIER

It is easy to become blasé about technological progress in this non-stop, 24/7, digital-everything-always-and-everywhere era. We take technological advances almost for granted and are frustrated when an app that streams the latest Hollywood movies crashes, or a smartphone which has many times the processing power of a 1980s Cray 2 supercomputer does not fire up the moment we press the "on" button.

We forget that it was not always this easy. Not so long ago, we had to go to libraries to look up quotations and insert compact discs into an audio system to play music. Transmitting even tiny amounts of data was complicated by today's standards; sometimes we had to strap bulky acoustic couplers onto a fixed telephone and wait for the modem to screech. As the German sociologist Hartmut Rosa has pointed out, we live in an age of acceleration in which the art of saving time has reached unprecedented heights thanks to technology, but we nonetheless feel that we must run faster just to stay put.[28]

Even by these standards, however, some of the most recent developments in robotics, artificial intelligence, and machine learning are noteworthy for the advances they represent. We are on the cusp of a new automation age in which technologies not only do things that we thought only humans could do, but also can increasingly do them at a superhuman level of performance. In this report, we focus on the adoption and implications of automation technologies rather than on the technologies themselves. However, by way of introduction, this chapter lays out some key areas of recent technical advances—and where remaining technical obstacles must still be overcome to achieve the full promise of workplace automation.[29]

AUTOMATION TECHNOLOGIES ARE INCREASINGLY OUTPERFORMING HUMANS

Physical robots have been around for a long time in manufacturing, but now we are seeing much more flexible, safer, and less expensive robots engaging in service activities—and improving over time as they are trained by their human coworkers on the shop floor.[30] For example, some hospitals now regularly use automated systems for storing and dispensing medication in their pharmacies, eliminating human picking errors, and also have automated haul and transport for their clinical supplies.[31] The advances in cognitive tasks are no less striking. Software has long been able to outperform humans in some areas, such as financial-service transactions or route optimization for companies such as UPS.[32] Now, artificial intelligence is starting to encroach on activities that were previously assumed to require human judgment and experience. Exhibit 1 is a non-exhaustive list of some of the technologies and techniques that are being developed to enable automation of different work activities.

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28 Hartmut Rosa, *Social acceleration: A new theory of modernity*, Columbia University Press, 2013.

29 For a more detailed discussion of machine learning and deep learning technologies see the corresponding chapter in *The age of analytics: Competing in a data-driven world*, McKinsey Global Institute, December 2016.

30 Baxter robots by Rethink Robotics can now pick up items that are not precisely aligned, and then reorient and place them correctly. http://www.rethinkrobotics.com/baxter/what-makes-our-robots-different.

31 Swisslog offers a medication management system, www.swisslog.com/en/products. For a transport and logistics example, see www.aethon.com/tug/tughealthcare.

32 For example, insurance companies use novel pattern recognition to detect fraudulent claims, saving companies including GE millions of dollars annually. A 2014 study used US Securities and Exchange Commission filing data as well as social network analysis to determine clusters of insiders and correlated their trading patterns. See Tamersov Acar et al., *Large-scale insider-trading analysis: Patterns and discoveries*, Georgia Institute of Technology, August 2014.

Exhibit 1

Glossary of automation technologies and techniques

JANUARY 2017

This list is not comprehensive but is meant to illustrate some of the technologies and techniques that are being developed to enable automation of different work activities

Technologies and techniques		Description/examples
Artificial intelligence		Field of computer science specializing in developing systems that exhibit "intelligence." Often abbreviated as AI, the term was coined by John McCarthy at the Dartmouth Conference in 1956, the first conference devoted to this topic
	Machine learning	Subfield of artificial intelligence developing systems that "learn," i.e., practitioners "train" these systems rather than "programming" them
	Supervised learning	Machine learning techniques that train a system to respond appropriately to stimuli by providing a training set of sample input and desired output pairs. Supervised learning has been used for email spam detection by training systems on a large number of emails, each of which has been manually labeled as either being spam or not
	Transfer learning	Subfield of machine learning developing systems that store knowledge gained while solving one problem and applying it to a different but related problem. Often used when the training set for one problem is small, but the training data for a related problem is plentiful, e.g., repurposing a deep learning system trained on a large non-medical image data set to recognize tumors in radiology scans
	Reinforce-ment learning	Subfield of machine learning developing systems that are trained by receiving virtual "rewards" or "punishments" for behaviors rather than supervised learning on correct input-output pairs. In February 2015, DeepMind described a reinforcement learning system that learned how to play a variety of Atari computer games. In March 2016, DeepMind's AlphaGo system defeated the world champion in the game of Go
	Cognitive computing	Synonym for artificial intelligence
Neural networks	**Artificial neural network**	AI systems based on simulating connected "neural units," loosely modeling the way that neurons interact in the brain. Computational models inspired by neural connections have been studied since the 1940s
	Deep learning	Use of neural networks that have many layers ("deep") of a large number (millions) of artificial neurons. Prior to deep learning, artificial neural networks often only had three layers and dozens of neurons; deep learning networks often have seven to ten or more layers. The term was first used in 2000
	Convolution-al neural network	Artificial neural networks in which the connections between neural layers are inspired by the organization of the animal visual cortex, the portion of the brain that processes images, well suited for perceptual tasks. In 2012, the only entry using a convolutional neural network achieved an 84% correct score in the ImageNet visual recognition contest, vs. a winning score of 75% the year prior. Since then, convolutional neural networks have won all subsequent ImageNet contests, exceeding human performance in 2015, above 90%
	Recurrent neural network	Artificial neural networks whose connections between neurons include loops, well-suited for processing sequences of inputs. In November 2016, Oxford University researchers reported that a system based on recurrent neural networks (and convolutional neural networks) had achieved 95% accuracy in reading lips, outperforming experienced human lip readers, who tested at 52% accuracy.

SOURCE: John McCarthy et al, "A proposal for the Dartmouth summer research project on artificial intelligence, August 31, 1955," *AI Magazine*, volume 27, number 4, 2016; Hayit Greenspan, Bram van Ginneken, and Ronald M. Summers, "Deep learning in medical imaging: Overview and future promise of an exciting new technique," *IEEE Transactions on Medical Imaging*, volume 35, number 5, May 2016; Volodymyr Mnih, "Human-level control through deep reinforcement learning," *Nature*, February 25, 2015; Igor Aizenberg, Naum N. Aizenberg, and Joos P.L. Vandewalle, *Multi-valued and universal binary neurons: Theory, learning and applications*, Springer Science & Business Media, 2000; www.image-net.org; Yannis M. Assael et al, LipNet: End-to-end sentence-level lipreading," University of Oxford (forthcoming); McKinsey Global Institute analysis

Exhibit 1

Glossary of automation technologies and techniques (continued)

JANUARY 2017

This list is not comprehensive but is meant to illustrate some of the technologies and techniques that are being developed to enable automation of different work activities

Technologies and techniques	Description/examples	
Robotics	**Soft robotics**	Non-rigid robots constructed with soft and deformable materials that can manipulate items of varying size, shape and weight with a single device. Soft Robotics Inc. grippers can adaptively pick up soft foods (e.g., baked goods, tomatoes) without damaging them.
	Swarm robotics	Coordinated multi-robot systems, often involving large numbers of mostly physical robots
	Tactile/touch robotics	Robotic body parts (often biologically inspired hands) with capability to sense, touch, exhibit dexterity, and perform variety of tasks
	Serpentine robots	Serpentine looking robots with many internal degrees of freedom to thread through tightly packed spaces
	Humanoid robots	Robots physical similar to human beings (often bi-pedal) that integrate variety of AI and robotics technologies and are capable of performing variety of human tasks (including movement across terrains, object recognition, speech, emotion sensing, etc.). Aldebaran Robotics and Softbank's humanoid Pepper robot is being used to provide customer service in more than 140 Softbank Mobile stores in Japan
Automation product categories	**Autonomous cars and trucks**	Wheeled vehicles capable of operating without a human driver. In July 2016, Tesla reported that its cars had driven over 130 million miles while on "Autopilot." In December 2016, Rio Tinto had a fleet of 73 driverless trucks hauling iron ore 24 hours/day in mines in Western Australia
	Unmanned aerial vehicles	Flying vehicles capable of operating without a human pilot. The unarmed General Atomics Predator XP UAV, with roughly half the wingspan of a Boeing 737, can fly autonomously for up to 35 hours from take-off to landing
	Chatbots	AI systems designed to simulate conversation with human users, particularly those integrated into messaging apps. In December 2015, the General Services Administration of the US Government described how it uses a chatbot named Mrs. Landingham (a character from the television show *The West Wing*) to help onboard new employees
	Robotic process automation	Class of software "robots" that replicates the actions of a human being interacting with the user interfaces of other software systems. Enables the automation of many "back-office" (e.g., finance, human resources) workflows without requiring expensive IT integration. For example, many workflows simply require data to be transferred from one system to another

SOURCE: www.ald.softbankrobotics.com; *A tragic loss*, Tesla blog, June 30, 2016; *Resource revolution: Transformations beyond the supercycle*, McKinsey Global Institute, forthcoming in 2017; www.ga-asi.com/predator-xp; Jessie Young, *How a bot named Dolores Landingham transformed 18Fs onboarding*, www.18f.gsa.gov, December 15, 2015; McKinsey Global Institute analysis

Some of AI's exploits are less heralded than its victory over a human champion of the complex board game Go in March 2016.[33] For example, a project by Google's DeepMind and the University of Oxford has applied deep learning to a huge data set of BBC programs to create a lip-reading system. Trained using more than 5,000 hours of BBC TV programs, containing more than 100,000 sentences, it easily outperformed a professional human lip-reader. In tests on 200 randomly selected clips, the professional annotated just 12.4 percent of words without error, while the computer annotated 46.8 percent error-free—and many of its mistakes were small ones, such as leaving a plural "s" off the end of a word.[34]

Many other surprising technologies are making advances. Robot "skin" made of a piezoelectronic transistor mesh developed by Georgia Tech and covered in thousands of mechanical hairs is as sensitive as human skin and able to "feel" textures and find objects by touch.[35] In the social and emotional realm, Affectiva, a Boston-based company, uses advanced facial analysis to monitor emotional responses to advertisements and other digital media content, via a webcam.[36] In the United Kingdom, the University of Hertfordshire has developed a minimally expressive humanoid robot called KASPAR that operates as a therapeutic toy for children with autism. Having physical, human-like properties, yet being non-human, allows the children to investigate the human-looking features—for example, squeezing KASPAR's nose or tickling its toes—safely and in a way that would not be possible or appropriate with a real person.[37]

Such advances suggest that an idea toyed with by science fiction writers for at least a century—that of robots and other machines replacing men and women in the workplace on a large scale—could soon become a reality. We seem to be approaching a new frontier, but we have not arrived there quite yet.

WHERE THE BIGGEST REMAINING OBSTACLES LIE

The Czech writer Karel Capek first used the word "robot" in 1920, in a play about a factory in which androids created partly through a chemical process each do the work of two-and-a-half humans at a fraction of the cost. One of his characters explains: "Robots are not people. Mechanically they are more perfect than we are, they have an enormously developed intelligence, but they have no soul."[38] Today, mechanical perfection seems achievable, as robots become ever more adept at physical tasks, even if they are still wobbly on uneven terrain and consume a lot of energy. Through deep reinforcement learning, they can also untie shoelaces, unscrew bottle caps, and remove a nail from the back of a hammer.[39]

Their "intelligence," too, has progressed—but this is where the most formidable technical challenges still lie ahead. While machines can be trained to perform a range of cognitive tasks, they remain limited. They are not yet good at putting knowledge into context, let alone improvising. They have little of the common sense that is the essence of human experience and emotion. They struggle to operate without a pre-defined methodology. They are far more literal than people, and poor at picking up social or emotional cues. Sarcasm and irony

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33 Choe Sang-Hun, "Google's computer program beats Lee Se-dol in Go tournament," *New York Times*, March 15, 2016.

34 Hal Hodson, "Google's DeepMind AI can lip-read TV shows better than a pro," *New Scientist*, November 21, 2016.

35 Klint Finley, "Syntouch is giving robots the ability to feel textures like humans do," *Wired*, December 17, 2015.

36 http://www.affectiva.com/solutions/overview/.

37 Ricky Boleto, "Could robots help children with autism?" *BBC News*, March 10, 2014. See also the University of Hertfordshire web page for KASPAR, http://www.herts.ac.uk/kaspar/supporting-children-with-autism.

38 The word "robot" comes from "robota," the Slavic word for work. Karel Capek, *R.U.R. (Rossum's Universal Robots)*, 1920. The play is available at www.gutenberg.org. Capek initially called the creatures "labori" but was persuaded by his brother to change the name. *Science diction: The origin of the word "robot,"* NPR Science Friday, April 22, 2011.

39 Signe Brewster, "A strong robot hand with a softer side," *MIT Technology Review*, February 9, 2016; *Robots master skills with "deep learning" technique*, Kurzweil, May 22, 2015.

pass them by. They generally cannot detect whether a customer is upset at a hospital bill or a death in the family, and for now, they cannot answer "What do you think about the people in this photograph?" or other open-ended questions. They can tell jokes without really understanding them. They don't yet feel humiliation, fear, pride, anger, or happiness. They also struggle with disambiguation, unsure whether a mention of the word "mercury" refers to a planet, a metal, or the winged god of Roman mythology.

Moreover, while machines can replicate individual performance capabilities such as fine motor skills or navigation, much work remains to be done integrating these different capabilities into holistic solutions where everything works together seamlessly. Combining a range of technologies will be essential for workplace automation, but engineering such solutions—whether for hardware or software—is a difficult process. The creation of solutions that solve specific problems in the workplace is work that will have to be done as individual technical challenges are overcome in the lab. Even once the technical feasibility issues have been resolved and the technologies become commercially available, it can take years before they are adopted.

Yet, given the speed with which technological advances are happening, reaching and crossing the next frontier may just be a question of time. Moore's law—that the number of transistors in a dense integrated circuit doubles approximately every two years—may be slowing, but we are still seeing massive increases in computing power. Machine learning and its subset deep learning continue to advance rapidly, while traditional AI algorithms become more versatile and powerful. Cloud computing and other technologies are opening new possibilities for more people to become involved in innovation. Academic research in these areas, especially in artificial intelligence, has increased significantly, and global markets are taking notice, with growing corporate investment in research and development.

When large-scale automation does come to the workplace, what will that mean for the economy, for jobs, and for the future of work itself? And how fast could it happen?

Such existential questions are easier to answer through fiction. Capek's 1920 play about robots ends with the destruction of mankind and robots discovering the meaning of love. This report, by contrast, seeks to establish a fact base with which to address these issues and a foundation for a more informed dialogue. Robots may not have a soul, but their potential impact on the global economy can be calculated.

A man works on a robot at a digital factory in The Hague that produces carbon plates for the aircraft industry.

2. THE TECHNICAL POTENTIAL FOR AUTOMATION

The speed with which automation technologies are emerging, and the extent to which they could disrupt the world of work, may appear daunting but is not unprecedented. Technological change has reshaped the workplace continually over the past two centuries since the Industrial Revolution, and even earlier (see Box 1, "What history teaches us about the effect of technological change on work, employment, and productivity"). Nonetheless, the latest technological developments will touch every job in every sector and in every country. The advances we described in the previous chapter all have practical applications in the workplace, and in some cases they have already been adapted, integrated, and deployed. Sophisticated machines are replacing human labor in workplaces from factories to fast-food restaurants. They are becoming a part of everyday life in fields from journalism to law to medicine; at the University of Tokyo, for example, IBM's Watson made headlines in 2016 by diagnosing in a 60-year-old woman a rare form of leukemia that had eluded her doctors for months.[40]

These technologies bring with them progress, productivity improvements, increased efficiencies, safety, and convenience, but they also raise difficult questions about the broader impact of automation on the workforce as a whole. Think tanks and organizations such as the World Economic Forum are forecasting the likelihood of major job substitution by automation.[41] Some academic studies estimate that close to 50 percent of US and European jobs could be automated, although other studies put that figure much lower (see the table "Overview of select recent studies on the impact of automation and the future of work," page 21).

Some of these projections focus on occupations perceived to be at risk.[42] Our approach is substantially different: we consider work *activities* a more relevant and useful basis for analysis than *occupations*. The reason for this is that, within sectors, every occupation consists of a number of constituent activities that may have a different technical potential for automation. A typical retail salesperson, for example, will spend some time interacting with customers, stocking shelves, or ringing up sales. Machines can already outperform humans in some of these activities—they are highly adept at managing warehouse inventory, for example—and at least one fashion company has a bot that advises clients, via their mobile phones, about the best lipstick match.[43] But computers and machines are far less adept than humans at sensing the emotional state of customers or understanding context. For example, no robot yet has the capacity to sense a distressed client and propose offering him or her a glass of water or a cup of tea.

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40 Bernie Monegain, "IBM Watson pinpoints rare form of leukemia after doctors misdiagnosed patient," *Healthcare IT News*, August 8, 2016.

41 The World Economic Forum has predicted that more than five million jobs could be lost to robots in 15 major developed and emerging economies over the next five years. *The future of jobs: Employment, skills, and workforce strategy for the fourth Industrial Revolution*, World Economic Forum, January 2016.

42 The Oxford University study, for example, focuses on occupations that it categorizes as being susceptible to automation. Carl Benedikt Frey and Michael A. Osborne, *The future of employment: How susceptible are jobs to computerization?* Oxford Martin School, September 17, 2013.

43 "Sephora debuts two new bot-powered beauty tools for Messenger," PR Newswire, November 2, 2016.

Box 1. What history teaches us about the effect of technological change on work, employment, and productivity

The fear of technological innovation destroying jobs and displacing workers dates back several hundred years, even before the Luddite movement in Britain during the Industrial Revolution that gave its name to militant technophobia. The Luddites were textile mill workers in Nottingham who rioted in 1811 to destroy the new automated looms that threatened their livelihoods. Ever since, there has been no shortage of predictions that machines would replace human laborers, with possibly dire effects. Karl Marx wrote in 1858 that "the means of labor passes through different metamorphoses, whose culmination is the machine, or rather, an automatic system of machinery."[1]

In 1930, the British economist John Maynard Keynes coined the term "technological unemployment" to describe a situation in which innovation that economized the use of labor outstripped the pace at which new jobs could be created. Keynes warned that this was akin to a "new disease"—but he also described this malady as being a "temporary phase of maladjustment."[2]

More recently, in 1966, a report from the US National Commission on Technology, Automation, and Economic Progress, predicted that "in the new technology, machines and automated processes will do the routine and mechanical work. Human resources will be released and available for new activities beyond those that are required for mere subsistence. The great need is to discover the nature of this new kind of work, to plan it, and to do it. In the longer run, significant changes may be needed in our society—in education, for example—to help people find constructive and rewarding ways to use increasing leisure."[3]

One lesson of history is that deployment of new technologies in the past has led to new forms of work, including in cases when shifts in the activities performed in the workplace have been very substantial. In the United States, for example, the share of farm employment fell from 40 percent in 1900 to 2 percent in 2000; similarly, the share of manufacturing employment fell from 25 percent in 1950 to less than 10 percent in 2010.[4] In both cases, while some jobs disappeared, new ones were created, although what those new jobs would be could not be predicted at the time.

Technological innovation can create new demand and whole new industries. Printing is one example. When the *Times* of London in 1814 switched to a revolutionary steam-powered printing press invented by German engineer Friedrich Koenig, the newspaper's printers staged a revolt that was quelled only when the paper promised to keep on displaced workers. That prototype, which used steam from water heated by coal to drive the press, initially printed 1,100 pages per hour, or five times as many as the mechanical press that preceded it. By 1820, presses could print 2,000 sheets per hour. By 1828, that doubled to 4,000. Then came the invention of rotary presses, which in turn enabled huge rolls of paper to be loaded into the presses rather than individual sheets. By the 1860s,

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1 Karl Marx, *Grundrisse: Foundations of the critique of political economy*, 1858 (unpublished manuscript), available online at www.marxists.org/archive.

2 John Maynard Keynes, "Economic possibilities for our grandchildren," in *Essays in Persuasion*, Macmillan, 1933. The essay is available online at www.econ.yale.edu/smith/econ116a/keynes1.pdf.

3 *Technology and the American economy: Report of the National Commission on Technology, Automation, and Economic Progress*, US Department of Health, Education, and Welfare, 1966.

4 Stanley Lebergott, "Labor force and employment 1800–1960," in *Output, employment, and productivity in the United States after 1800*, Dorothy S. Brady, ed., NBER, 1966; World Bank data.

Box 1. What history teaches us about the effect of technological change on work, employment, and productivity (continued)

the most advanced presses could print 30,000 pages per hour. The arrival of electricity and the development of linotype and photomechanical processes able to reproduce photographs meant that by 1890, the *New York Herald* was able to print 90,000 copies of its four-page paper per hour, with color illustrations. This stream of innovation, combined with greater press freedom, drove the growth of a vibrant and fast-growing newspaper industry in the United States and Europe, creating millions of jobs in printing, journalism, and other related fields.[5]

More recent evidence at a macroeconomic level suggests the positive links between technological progress, productivity, and jobs continued through the 20th century. Positive gains in both productivity and employment have been reported in the United States in more than two-thirds of the years since 1929.[6] One-third of new jobs created in the United States in the past 25 years did not exist, or barely existed, 25 years ago.[7] However, in recent years, there has been a notable divergence between productivity and pay, and the labor share of income has declined in many advanced economies.[8]

The question today is whether this latest wave of innovation is by its nature substantially different from technological disruptions in the past. As automation makes inroads into the workplace, a critical concern is that technology-enabled automation could replace not just low-skill jobs—which is what happened in the past—but that it could affect all jobs. For now, there is an increasing bifurcation in the labor market between a dwindling number of high-skill jobs and many low-wage and low-skill service jobs.[9] As we detail later in this chapter, even high-paying occupations in sectors such as financial services are potentially susceptible to automation. Opinions are sharply divided about the medium- and long-term effects of this automation wave. In 2014, the Pew Research Center conducted a survey of technology professionals and economists and found that 48 percent of respondents believed new technologies would displace more jobs than they would create by 2025.[10]

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5 Elizabeth Eisenstein, *The printing press as an agent of change*, Cambridge University Press, 1980; Robert Hoe, *A short history of the printing press and of the improvements in printing machinery from the time of Gutenberg up to the present day*, 1902.

6 *Growth and renewal in the United States: Retooling America's economic engine*, McKinsey Global Institute, February 2011.

7 Ibid.

8 Josh Bivens and Lawrence Mishal, *Understanding the historic divergence between productivity and a typical worker's pay: Why it matters and why it's real*, Economic Policy Institute briefing paper number 406, September 2015; *Poorer than their parents? Flat or falling incomes in advanced economies*, McKinsey Global Institute, July 2016.

9 See David H. Autor and David Dorn, "The growth of low-skill service jobs and the polarization of the US labor market," *American Economic Review*, volume 103, number 5, August 2013, and Lawrence Mishel and Kar-Fai Gee, "Why aren't workers benefiting from labour productivity growth in the United States?" *International Productivity Monitor*, number 23, spring 2012.

10 Aaron Smith and Janna Anderson, *AI, robotics, and the future of jobs*, Pew Research Center, August 6, 2014. There has been a proliferation of books by competing schools of "techno-optimists" and "techno-pessimists." They notably include Erik Brynjolfsson and Andrew McAfee, *The second machine age: Work, progress, and prosperity in a time of brilliant technologies*, W. W. Norton & Company, 2014; and Robert Gordon, *The rise and fall of American growth: The US standard of living since the Civil War*, Princeton University Press, 2016; Martin Ford, *Rise of the robots: Technology and the threat of a jobless future*, Basic Books, 2015. Also see Jason Furman, "Is this time different? The opportunities and challenges of artificial intelligence," remarks at AI Now: The Social and Economic Implications of Artificial Intelligence Technologies in the Near Term conference in New York, July 7, 2016.

Using data from the US Bureau of Labor Statistics and O*Net, we have examined in detail more than 2,000 work activities for more than 800 occupations across the entire economy. We estimated the amount of time spent on these activities and the technical feasibility of automating each of them by adapting currently demonstrated technology. Having undertaken this analysis of the US economy, we extended our study to 45 other countries, using the most comparable data available in each.[44] This detailed research enables us to draw important conclusions about the technical feasibility of automation for the global economy today, as well as for individual professions within specific sectors, from US mortgage brokers to Indian farmers.

Our core findings are that the proportion of occupations that can be fully automated by adapting currently demonstrated technology—in other words, all of their activities could be automated—is very small, less than 5 percent in the United States. Automation will nonetheless affect almost all occupations, not just factory workers and clerks, but also landscape gardeners and dental lab technicians, fashion designers, insurance sales representatives, and CEOs, to a greater or lesser degree. The automation potential of these occupations depends on the types of work activity that they entail, but as a rule of thumb, about 60 percent of all occupations have at least 30 percent of activities that are technically automatable.

In the United States, the country for which we have the most complete data, about 46 percent of time spent on work activities across occupations and industries is technically automatable based on currently demonstrated technologies. Exhibit 2 shows the distribution range of this automation potential in the United States. On a global scale, we calculate that the adaptation of currently demonstrated automation technologies could affect 50 percent of working hours in the global economy. This potential corresponds to the equivalent of 1.2 billion workers and $14.6 trillion in wages. Among countries, the potential ranges between 41 and 56 percent, with just four countries—China, India, Japan, and the United States—accounting for just over half the total wages and workers. The potential could also be large in Europe: according to our analysis, the equivalent of 62 million full-time workers and more than $1.9 trillion in wages are associated with technically automatable activities in the continent's five largest economies alone—France, Germany, Italy, Spain, and the United Kingdom.

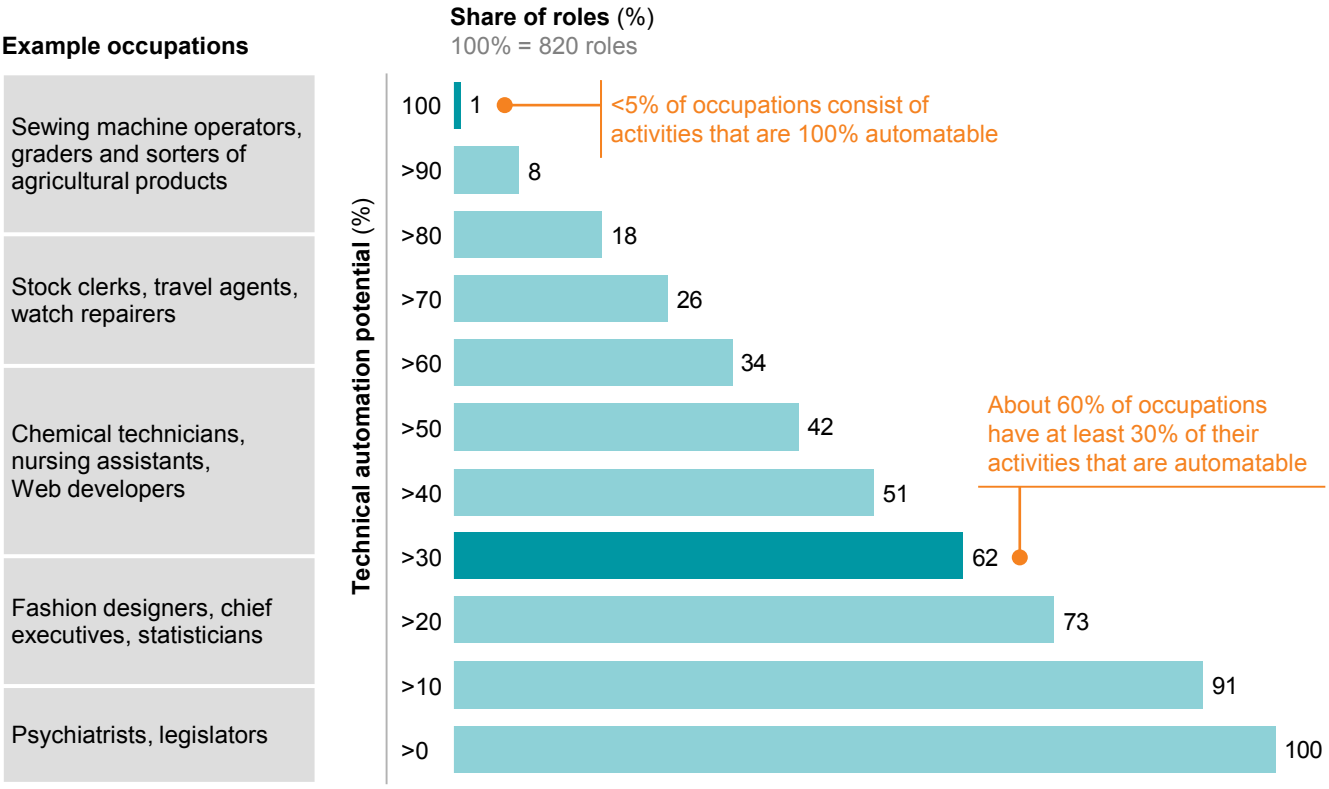
In this chapter we describe in detail the technical potential for automation in different sectors of the economy and for the global economy as a whole, based on the state of technology today. We explain how we calculate technical automation potential and, based on that methodology, we identify categories of activities that are the most and the least susceptible to automation. This enables us to provide detailed estimates of the technical automation potential of sectors and of different occupations within those sectors. We conclude with an examination of similarities and differences between countries, both advanced and emerging economies, for a global view of automation and its very substantial potential to transform the world of work.

[44] For full details of our methodology, see the technical appendix.

Exhibit 2

While few occupations are fully automatable, 60 percent of all occupations have at least 30 percent technically automatable activities

Automation potential based on demonstrated technology of occupation titles in the United States (cumulative)[1]



1 We define automation potential according to the work activities that can be automated by adapting currently demonstrated technology.

SOURCE: US Bureau of Labor Statistics; McKinsey Global Institute analysis

ESTIMATING THE TECHNICAL POTENTIAL FOR WORKPLACE AUTOMATION

Humans at work carry out a wide variety of activities—whether stapling documents, examining spreadsheets, meeting clients, interviewing potential new recruits, lifting crates in a store, or planting corn in a field—without consciously analyzing the exact skill sets they are using. In fact, each of these actions requires a combination of innate or acquired capabilities, ranging from manual dexterity to social perceptiveness. In order to understand and map performance requirements for machines in the workplace, we developed a detailed framework of 18 human capabilities, including physical, emotional, and cognitive ones.

It is important to note that when we discuss automation potential in this chapter, we refer to the technical potential for automation by adapting technologies that have already been demonstrated. As the technology becomes more advanced, that potential will also evolve. While this chapter focuses on technologies that have been developed today, later chapters estimate the speed with which the technological capabilities are likely to improve and be adopted in the workplace.

It should also be noted that technical feasibility is not the same as actual implementation of automation, nor a complete predictor that an activity will be automated. A second factor to consider is the cost of developing and deploying both the hardware and the software solutions for automation. The cost of labor and related supply and demand dynamics represent a third factor: if workers are in abundant supply and significantly less expensive than automation, this could be a decisive argument against adoption. A fourth factor to consider is the benefits beyond labor substitution, including higher levels of output, better quality, and fewer errors. The economic value of these benefits is often larger than that of reducing labor costs. Regulatory and social acceptance issues, such as the degree to which machines are acceptable in any particular setting, must also be weighed. A robot may, in theory, be able to replace some of the functions of a nurse, for example. But for now, the prospect that this might actually happen in a highly visible way could prove unpalatable for many patients, who expect and trust human contact. The pace at which automation will take hold in a sector or occupation reflects a subtle interplay between these factors and the trade-offs among them.

A framework of capabilities to understand the performance requirements of work activities

The framework of 18 capabilities that we developed to assess automation potential addresses a wide range of performance requirements. Many of these capabilities correspond to the technologies we discussed in the previous chapter. They cover five areas: sensory perception, cognitive capabilities, natural language processing, social and emotional capabilities, and physical capabilities (Exhibit 3).

- **Sensory perception.** This includes visual perception, tactile sensing, and auditory sensing, and involves complex external perception through integrating and analyzing data from various sensors in the physical world.

- **Cognitive capabilities.** A range of capabilities is included in this category including recognizing known patterns and categories (other than through sensory perception); creating and recognizing novel patterns and categories; logical reasoning and problem solving using contextual information and increasingly complex input variables; optimization and planning to achieve specific objectives given various constraints; creating diverse and novel ideas or a novel combination of ideas; information retrieval, which involves searching and retrieving information from a large range of sources; coordination with multiple agents, which involves interacting with other machines and with humans to coordinate group activity; and output articulation and presentation, which involves delivering outputs other than through natural language. These could be automated production of pictures, diagrams, graphs, or mixed media presentations.

- **Natural language processing.** This consists of two distinct parts: natural language generation, which is the ability to deliver spoken messages, including with nuanced human interaction and gestures, and natural language understanding, which is the comprehension of language and nuanced linguistic communication in all its rich complexity.

- **Social and emotional capabilities.** This consists of three types of capability: social and emotional sensing, which involves identifying a person's social and emotional state; social and emotional reasoning, which entails accurately drawing conclusions based on a person's social and emotional state, and determining an appropriate response; and social and emotional output, which is the production of an appropriate social or emotional response, both in words and through body language.

- **Physical capabilities.** This includes gross motor skills, fine motor skills, navigation, and mobility. These capabilities could be implemented by robots or other machines manipulating objects with dexterity and sensitivity, moving objects with multidimensional motor skills, autonomously navigating in various environments, and moving within and across various environments and terrain.

Exhibit 3

Current technologies have achieved different levels of human performance across 18 capabilities

Below median | Median | Top quartile

	Automation capability	Capability level[1]	Description (ability to …)
Sensory perception	Sensory perception		Autonomously infer and integrate complex external perception using sensors
Cognitive capabilities	Recognizing known patterns/categories (supervised learning)		Recognize simple/complex known patterns and categories other than sensory perception
	Generating novel patterns/ categories		Create and recognize new patterns/categories (e.g., hypothesized categories)
	Logical reasoning/ problem solving		Solve problems in an organized way using contextual information and increasingly complex input variables other than optimization and planning
	Optimization and planning		Optimize and plan for objective outcomes across various constraints
	Creativity		Create diverse and novel ideas, or novel combinations of ideas
	Information retrieval		Search and retrieve information from a large scale of sources (breadth, depth, and degree of integration)
	Coordination with multiple agents		Interact with others, including humans, to coordinate group activity
	Output articulation/ presentation		Deliver outputs/visualizations across a variety of mediums other than natural language
Natural language processing	Natural language generation		Deliver messages in natural language, including nuanced human interaction and some quasi language (e.g., gestures)
	Natural language understanding		Comprehend language, including nuanced human interaction
Social and emotional capabilities	Social and emotional sensing		Identify social and emotional state
	Social and emotional reasoning		Accurately draw conclusions about social and emotional state, and determine appropriate response/action
	Social and emotional output		Produce emotionally appropriate output (e.g., speech, body language)
Physical capabilities	Fine motor skills/dexterity		Manipulate objects with dexterity and sensitivity
	Gross motor skills		Move objects with multidimensional motor skills
	Navigation		Autonomously navigate in various environments
	Mobility		Move within and across various environments and terrain

1 Assumes technical capabilities demonstrated in commercial products, R&D, and academic settings; compared against human performance.

SOURCE: McKinsey Global Institute analysis

We estimated the level of performance in each of these capabilities that is required to successfully perform each work activity, categorizing whether the capability is required at all, and if so, whether the required level of performance is at roughly a median human level, below median human level, or at a high level of performance (for example, the top 25th percentile).[45] We also assessed the performance of existing technologies today against the same criteria.

This framework enabled us to assess the state of technology today and the potential to automate work activities in all sectors of the economy by adapting currently demonstrated technologies. By evaluating the technologies across a spectrum of performance, we have also been able to take into account their potential evolution in the future and resulting incremental effect on workplace activities. A detailed account of our methodology is contained in the technical appendix. Our assessments are simplifications for modeling purposes that synthesize a variety of subcapabilities, not all of which consistently fall into the below-median, median, and top-quartile categories.

Machines will need to be able to use many of these capabilities together in the workplace, as humans do

The 18 capabilities we have identified should not be taken in isolation. They are closely interconnected.

Let us return to our retail salesperson, by way of example, to show the interplay of these capabilities. Daily activities may include greeting customers, answering questions about products and services, cleaning and maintaining work areas, demonstrating product features, and processing sales and transactions. To carry out this range of activities requires almost the full spectrum of these capabilities. It starts with the greeting of customers. A skilled salesperson will identify the social and emotional state of a customer, accurately draw conclusions about how to react to that social and emotional state, and through body language, tone of voice, and choice of vocabulary, provide an emotionally appropriate response. Cognitive capabilities will be fully used, too. Listening to what a customer says and responding requires the ability to understand and generate natural language. Other cognitive capabilities employed are the ability to retrieve information ("do we have these shoes in stock?"); to reason logically and solve problems ("we don't have them in your size in black, but we do have them in red or brown"); to coordinate with multiple agents ("I'll have one of my colleagues determine if we have the item in stock"), and creativity ("try the purple pair, they're very fashionable this year and will suit you well"). Physical capabilities are likewise also needed. They include mobility and navigation (walking to the stockroom), gross motor skills (taking the shoe box off a shelf in the stockroom), and fine motor skills (tying a lace).

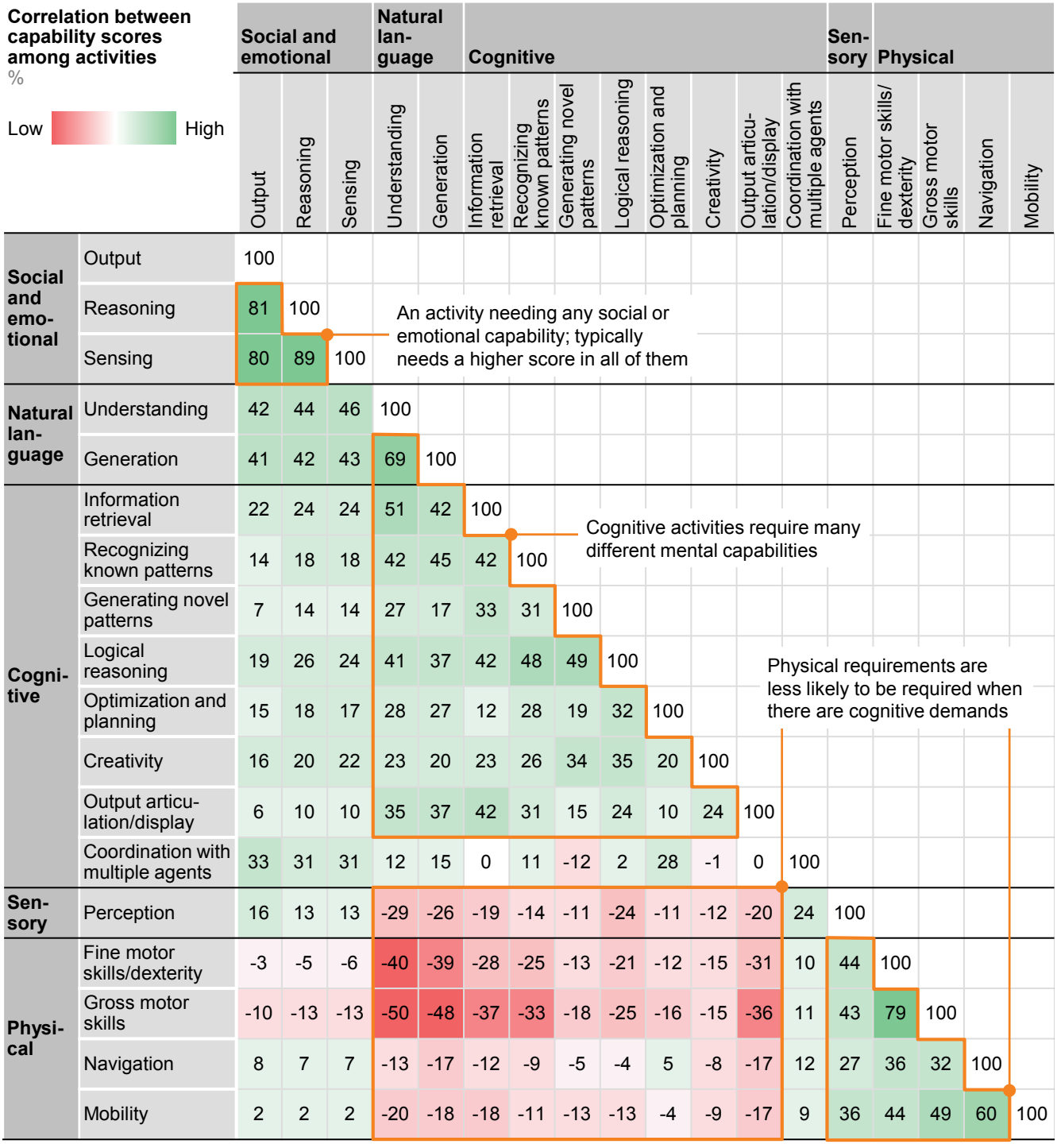
For now, automation technologies do not have this full range of capabilities to perform at the same level as humans, and for many problems, they have yet to be seamlessly integrated into solutions. Combinations of social, cognitive, and physical capabilities are required for many activities, and we do see patterns about which capabilities are often required together (Exhibit 4). For example, an activity that needs any social or emotional capability typically needs all of them—sensing, reasoning, and output. Likewise, an activity requiring one form of physical capability such as fine motor skills or mobility tends to require multiple physical capabilities, including gross motor skills and navigation. However, cognitive capabilities can occur in combination with many different capabilities. There is an overlap between creativity and optimization and planning, for example, but one can do without the other. Coordinating with multiple agents does not automatically entail information retrieval, logical reasoning, or

[45] Among the many factors that define levels of performance are the acceptable error rates, particularly for sensory and cognitive activities. For instance, the consequences of false positives or negatives when making certain law enforcement or health-care judgments could be much more significant than for other judgments in the entertainment industry.

generating novel patterns. Moreover, where there are cognitive demands, physical demands are less likely to be required.

Exhibit 4

Many capabilities tend to be required together for specific activities



		Output	Reasoning	Sensing	Understanding	Generation	Information retrieval	Recognizing known patterns	Generating novel patterns	Logical reasoning	Optimization and planning	Creativity	Output articulation/display	Coordination with multiple agents	Perception	Fine motor skills/dexterity	Gross motor skills	Navigation	Mobility
Social and emotional	Output	100																	
	Reasoning	81	100																
	Sensing	80	89	100															
Natural language	Understanding	42	44	46	100														
	Generation	41	42	43	69	100													
Cognitive	Information retrieval	22	24	24	51	42	100												
	Recognizing known patterns	14	18	18	42	45	42	100											
	Generating novel patterns	7	14	14	27	17	33	31	100										
	Logical reasoning	19	26	24	41	37	42	48	49	100									
	Optimization and planning	15	18	17	28	27	12	28	19	32	100								
	Creativity	16	20	22	23	20	23	26	34	35	20	100							
	Output articulation/display	6	10	10	35	37	42	31	15	24	10	24	100						
	Coordination with multiple agents	33	31	31	12	15	0	11	-12	2	28	-1	0	100					
Sensory	Perception	16	13	13	-29	-26	-19	-14	-11	-24	-11	-12	-20	24	100				
Physical	Fine motor skills/dexterity	-3	-5	-6	-40	-39	-28	-25	-13	-21	-12	-15	-31	10	44	100			
	Gross motor skills	-10	-13	-13	-50	-48	-37	-33	-18	-25	-16	-15	-36	11	43	79	100		
	Navigation	8	7	7	-13	-17	-12	-9	-5	-4	5	-8	-17	12	27	36	32	100	
	Mobility	2	2	2	-20	-18	-18	-11	-13	-13	-4	-9	-17	9	36	44	49	60	100

SOURCE: McKinsey Global Institute analysis

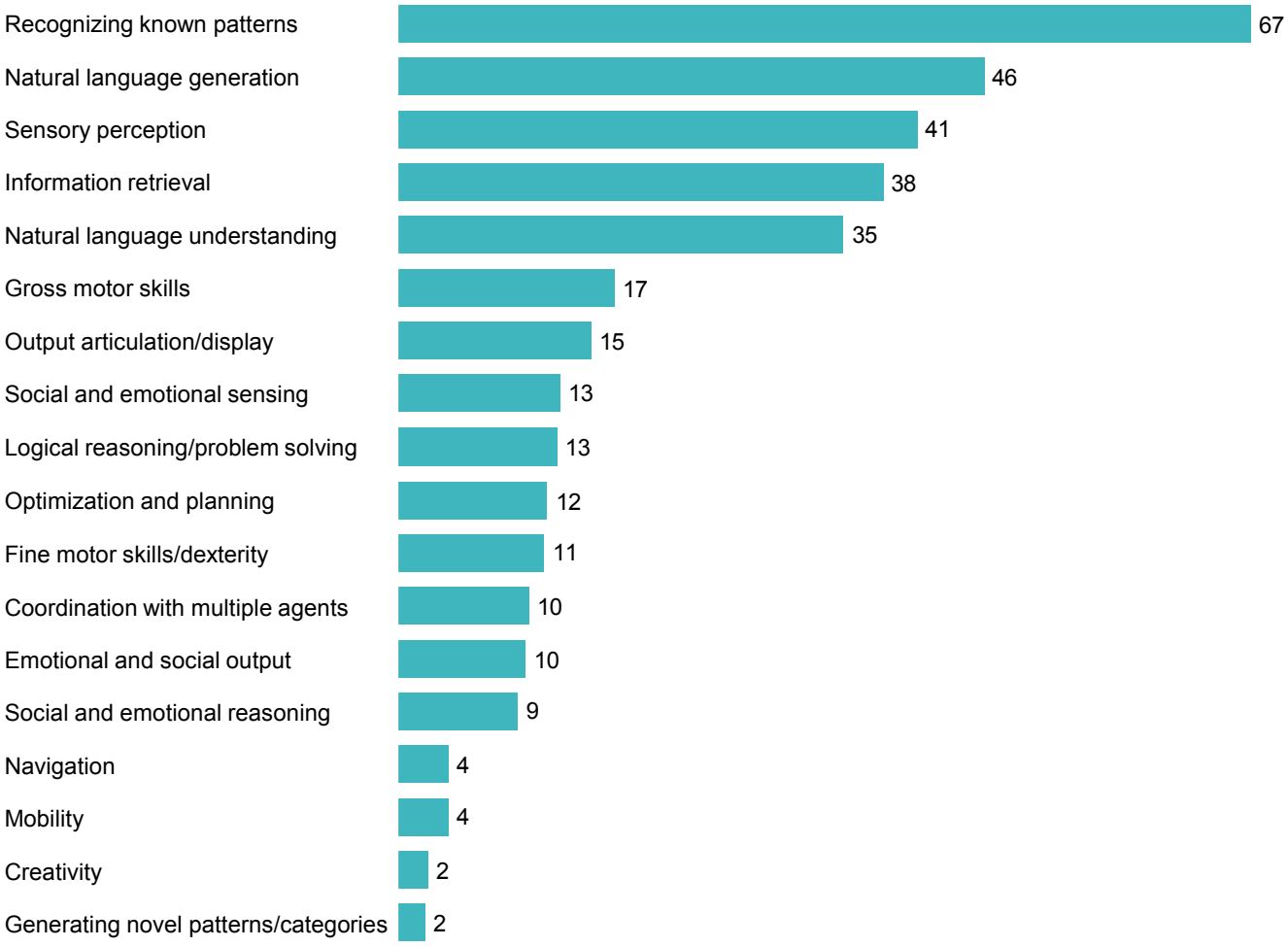
When machines can take on workplace activities, the nature of work will change. Today, only about 10 percent or less of the average human worker's time at work is spent using capabilities such as emotional reasoning and creativity, which many people would describe as being a core part of the human experience. The capability most used is recognizing known patterns, followed by natural language generation (for example, speaking), sensory

perception, information retrieval, and natural language understanding (Exhibit 5). By allowing machines to handle more mundane activities, automation could free up women and men to use their creative and other talents more than they do now.

Exhibit 5

Recognizing known patterns and natural language generation are the two most-used capabilities in work activities

Time spent by US workers on activities that require median or higher levels of human performance for each capability
% of time



SOURCE: US Bureau of Labor Statistics; McKinsey Global Institute analysis

Gauging the automation potential of occupations and sectors of the economy through analysis of their constituent activities

Applying our methodology to the more than 2,000 activities across all sectors of the economy carried out by the US workforce—and subsequently adopting similar methodology for the global workforce—we found that many types of activities share common characteristics that are readily grouped into categories. For example, processing data is a very frequent activity common to a large range of occupations in different sectors, as is carrying out repetitive physical movement. By analyzing the amount of time spent on each of these categories of activity, we were able to estimate the technical automation potential of hundreds of occupations across the economy. We have also analyzed the implications across wage rates. As noted, the technical ability to automate is only one element that will lead to automation actually being deployed in the workplace; given

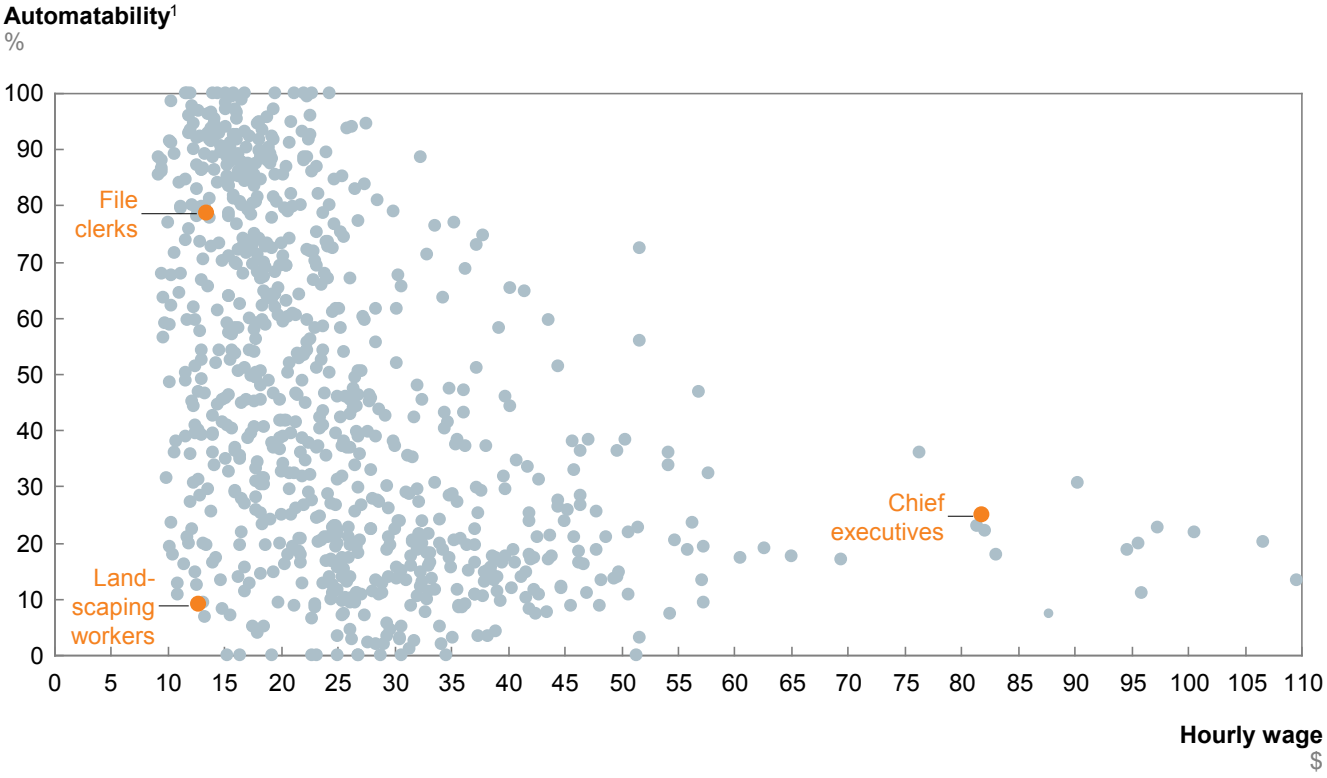
hardware and software costs and relative wage levels, a coherent business case needs to be made, and regulatory, social, and organizational issues also play a role.

Hourly wage rates are not strong predictors of automation potential

Occupations across the spectrum of the economy, from CEO to metal welders, have a range of automation potential based on today's technologies. Technically automatable activities represent about $2.7 trillion of addressable wages in the United States, or about 46 percent of the total hours worked. Automation is sometimes depicted as primarily affecting particular groups of workers depending on their wage levels. Our analysis finds that while there is a negative correlation between wage rates and technical automation potential, there is a large amount of variation, so the hourly wage rate is not a strong predictor of technical automation potential.[46] In fact, a significant proportion of highly paid work, not just low-wage work, can be automated (Exhibit 6).

Exhibit 6

Both low and high-wage occupations have significant technical automation potential



1 Our analysis used "detailed work activities," as defined by O*NET, a program sponsored by the US Department of Labor, Employment and Training Administration.

SOURCE: US Bureau of Labor Statistics; McKinsey Global Institute analysis

People in the lowest wage group, earning less than $15 per hour, carry out work activities that have among the highest potential for automation, and as a whole a majority (51 percent) of this group's activities is automatable. However, those earning between $15 and $30 per hour have an automation potential of 46 percent, which is close to the average for the economy as a whole. Above this $15 to $30 wage level, there is no clear pattern or correlation between wages and the automation potential of the work. More than 17 million

[46] Using a linear model, we find the correlation between wages and automatability (the percentage of time spent on activities that can be automated by adapting currently demonstrated technology) in the US economy to be significant (p-value < 0.01), but with a high degree of variability (r2 = 0.19).

American workers earn between $30 and $45 per hour, but the automation potential of this group is similar to that of people earning $90 to $105 per hour, for example.

Similarly, higher education attainment levels and work experience are correlated with lower technical automation potential, but there is also a great deal of variability.

Technical potential is an important consideration, but other factors including cost of automation and wage levels also weigh on the decision to automate

The deployment of automation technologies in the workplace depends on a range of factors, of which the availability of the technology itself is an important one, but not the only one. That it is technically possible for a robot to carry out an activity does not mean that it will necessarily be deployed to do so in the workplace. Four other factors also need to be taken into consideration. The pace at which activities are automated and the extent of that automation reflects a subtle interplay between these factors and the trade-offs among them.

The first factor is the cost. Buying, adapting, and integrating the necessary hardware and software to automate activities can be expensive and complex, and before doing so, employers need a strong business case. Will machines in fact be able to undertake the tasks at hand less expensively and more efficiently, or do human labor and skills still have the edge? While it may be possible to automate service at a fast-food restaurant, the cost of the machines compared to the cost of humans earning a minimum wage will need to be calculated and considered. Indeed, a more clear-cut case for automation may come as higher-wage jobs are reviewed for their technical feasibility to be automated.

The cost of labor and the related supply and demand dynamics may thus play a significant role in decisions about automation, and are the second factor. If workers are in abundant supply and significantly less expensive than automation, this could be a decisive argument against automation. We calculate that just over $1 trillion in wages could be economically automated with a technology cost of $20 per hour, and $2 trillion could be captured with an automation cost of $10 per hour. Our analysis at the level of individual activities supports the argument that some occupations in the middle of the income and skill distribution are more susceptible to automation than others at the top and bottom (see Box 2, “Labor market polarization and the technical automation potential of occupation families).

Box 2. Labor market polarization and the technical automation potential of occupation families

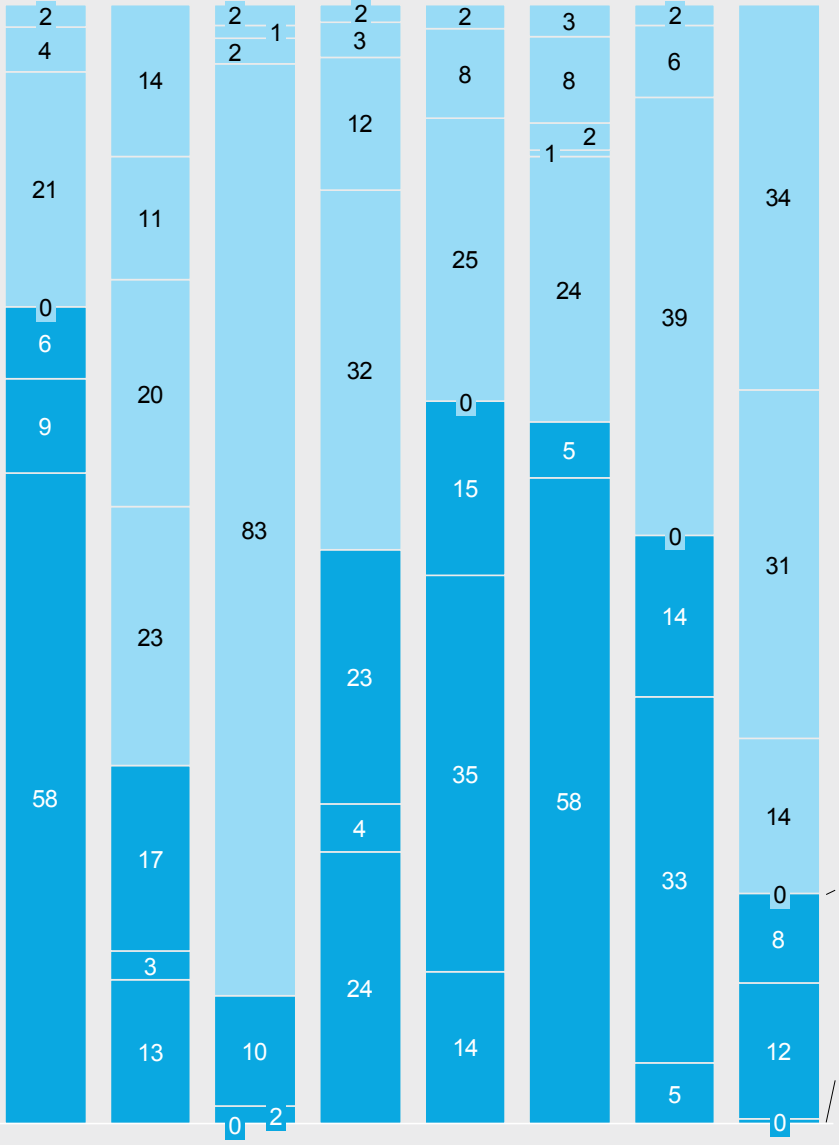
A body of work in the economics literature documents “polarization” in the labor markets of developed countries, in which “wage gains went disproportionately to those at the top and at the bottom of the income and skill distribution, not to those in the middle.”[1] These observations have largely been based on workforce data from national statistical agencies. Our analysis at the level of individual activities supports the argument that some occupations in the middle of the income and skill distribution are more susceptible to automation than others at the top and bottom. As depicted in Exhibit 7, occupation families (an aggregation of individual occupations) for transportation, office administration, and production, in the middle of the distribution, have higher percentages of activities with high technical automation potential (collecting data, processing data, and predictable physical activities) than other occupation families lower and higher in the distribution. However, one occupation family at the low end of the income distribution, food preparation, has the highest percentage of time in activities with a high technical potential for automation. Furthermore, as technology continues to develop over time, the automation potential of different activities will also increase.

[1] David H. Autor, “Why are there still so many jobs? The history and future of workplace automation,” *Journal of Economic Perspectives*, volume 29, number 3, 2015.

Exhibit 7

Mix of activity types in selected occupation families

% of activity hours spent arranged by weighted hourly wage in $



Occupation family[2]	Food prepa-ration	Per-sonal care	Building/ grounds cleaning	Trans-por-tation	Office admini-stration	Produc-tion	Sales	Manage-ment
Weighted hourly wage $	10.41	11.76	12.45	16.12	16.56	16.98	17.79	49.24
FTEs employed Million	11.85	3.89	4.26	8.85	20.96	8.39	13.95	6.54

1 Data for the United States only.
2 Aggregations of individual occupations. Eight occupation families selected from a total of 22.
NOTE: Numbers may not sum due to rounding.

SOURCE: McKinsey Global Institute analysis

A third factor to consider are the benefits of automation beyond labor substitution. These can include higher levels of output, raised quality, speed, agility, safety, and fewer errors. The potential savings from these benefits can be larger than those from labor costs.

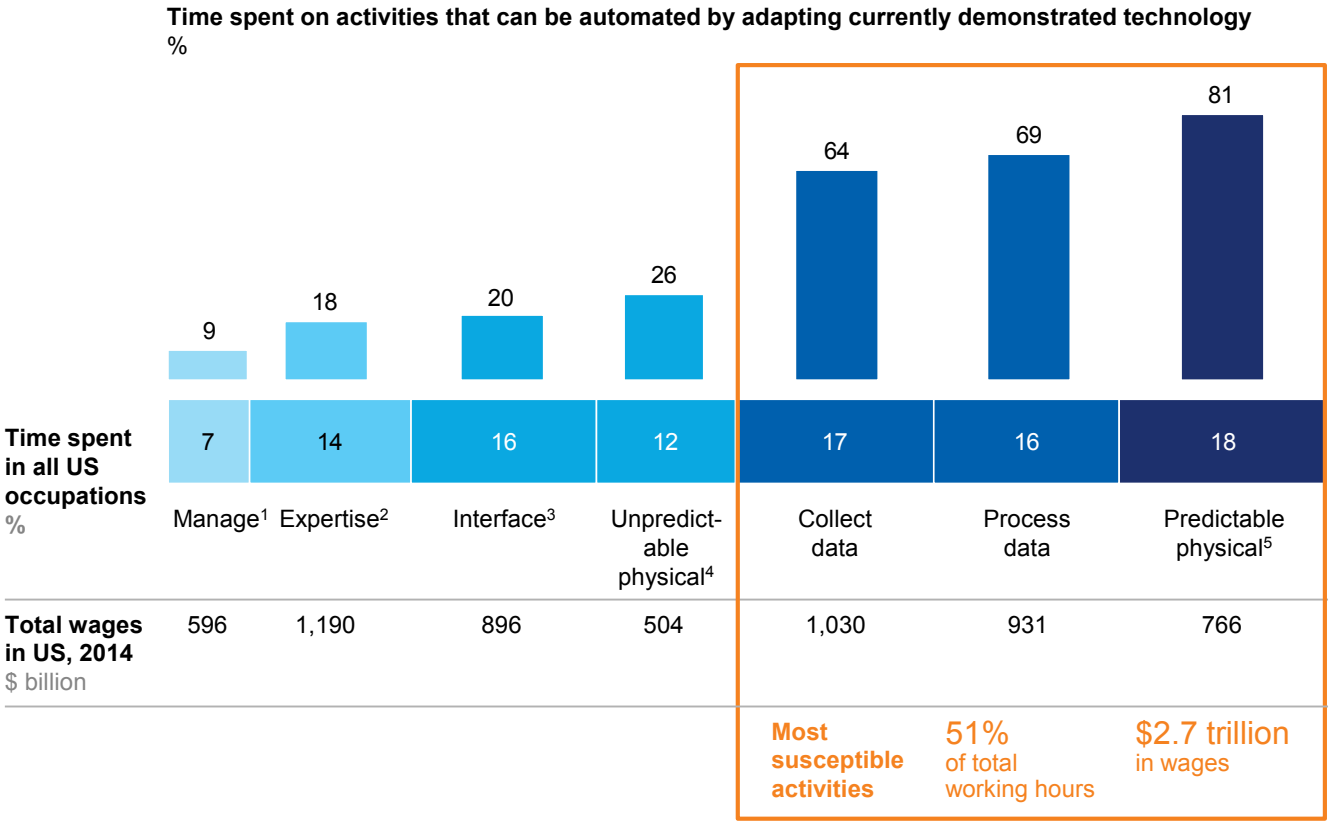
Finally, there is the issue of social and regulatory acceptability of automation. While self-driving autos and trucks are undergoing tests in both the United States and Europe, they will be able to operate without human co-drivers only when regulators are comfortable with them doing so. Social acceptance may be even more difficult. While a robot in theory could carry out some functions of a nurse or a home-care help, the human beings on the receiving end of their care may balk at the idea.

Differentiating work activities into seven high-level categories

Across the more than 2,000 work activities across the US economy that we analyzed using Bureau of Labor Statistics data, we identified seven high-level categories of work activity. Each of these categories has a different potential for automation. Three categories have the highest technical potential for automation: performing physical activity and operating machinery in predictable environments, processing data, and collecting data. The other four high-level categories have a considerably lower potential for automation: performing physical activities and operating machinery in unpredictable environments; interfacing with stakeholders; applying expertise to decision making, planning, and creative tasks; and, least susceptible to automation, managing and developing people (Exhibit 8).

Exhibit 8

Three categories of work activities have significantly higher technical automation potential



1 Managing and developing people.
2 Applying expertise to decision making, planning, and creative tasks.
3 Interfacing with stakeholders.
4 Performing physical activities and operating machinery in unpredictable environments.
5 Performing physical activities and operating machinery in predictable environments.
NOTE: Numbers may not sum due to rounding.

SOURCE: US Bureau of Labor Statistics; McKinsey Global Institute analysis

Performing physical activities and operating machinery in predictable environments

Almost one-fifth of the time spent in US workplaces involves performing physical activities and operating machinery in predictable environments, which have the highest automation potential of our seven categories, 81 percent. Currently demonstrated technology works best in these environments, where changes are relatively easy to anticipate. Physical activities in predictable environments figure prominently in sectors such as manufacturing, accommodation and food services, and retailing. That makes these sectors among the most susceptible to automation. Exhibit 9 shows a breakdown of different sectors of the economy based on the seven high-level categories.

In manufacturing, for example, performing physical activities or operating machinery in a predictable environment represents one-third of the workers' overall time. The activities range from packaging products to loading materials on production equipment to welding to maintaining equipment. Because of the prevalence of such predictable physical work, almost 60 percent of all manufacturing activities could be automated. The overall potential, however, masks considerable variance. Within manufacturing, welders, cutters, solderers, and brazers, have an automation potential above 90 percent, for example, while that of customer service representatives is below 30 percent.

Manufacturing is the second most readily automatable sector in the US economy. A service sector occupies the top spot: accommodation and food services, where almost half of all labor time involves physical activities in predictable environments and the operation of machinery—including preparing, cooking, or serving food; cleaning food preparation areas; and preparing hot and cold beverages. According to our analysis, 73 percent of the activities workers perform in the accommodation and food services sector have the technical potential for automation.

Some of this potential is familiar. Automats, or automated cafeterias, for example, have long been in use. Now restaurants are testing new, more sophisticated concepts, such as self-service ordering or even robotic servers. Solutions such as Momentum Machines' hamburger-cooking robot, which can reportedly assemble and cook 400 burgers an hour, could automate a number of cooking and food preparation activities.[47]

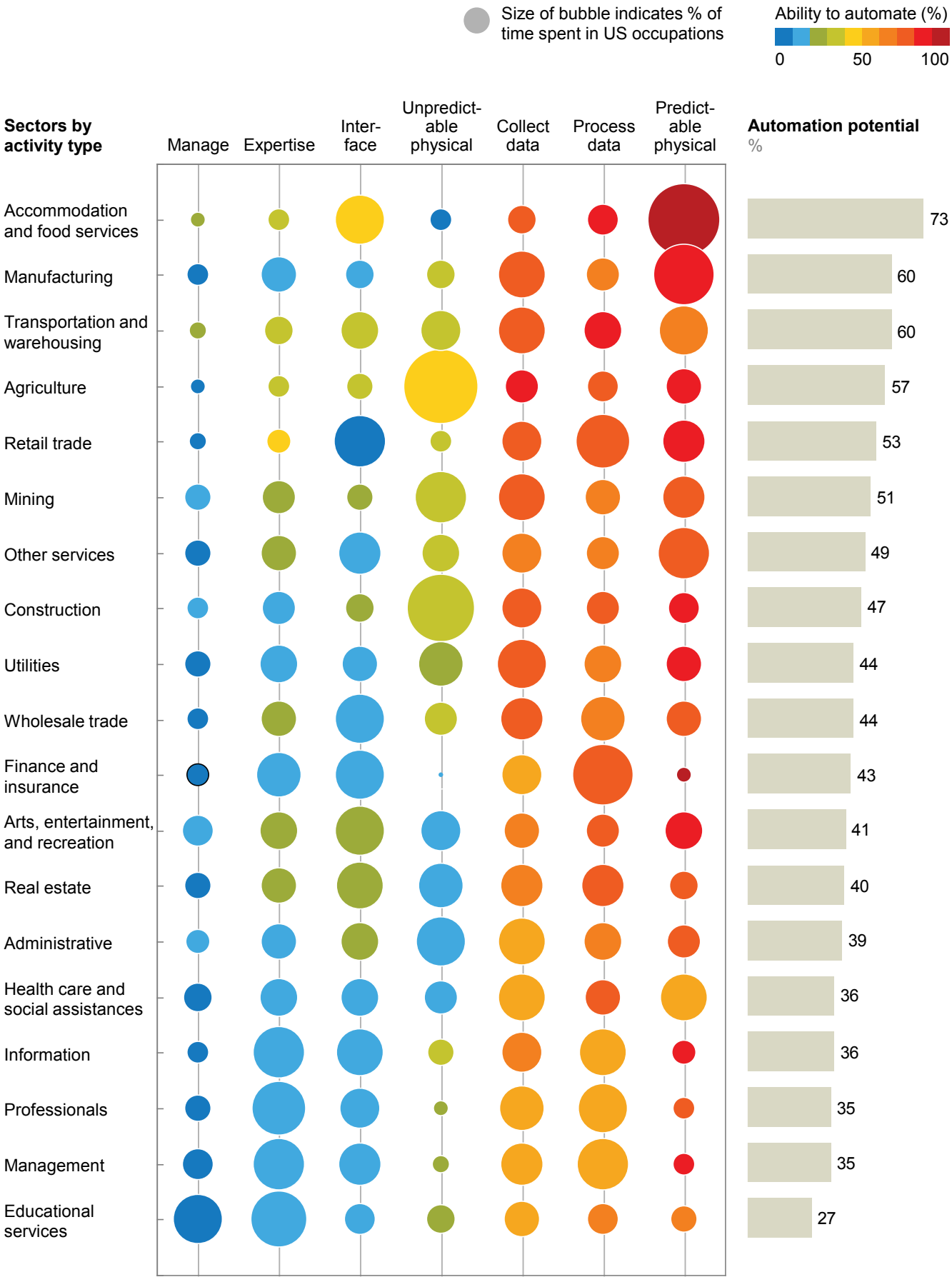
Data processing and data collection

Data processing is the second category most readily automatable (69 percent) and accounts for 16 percent of all the time spent working in the United States. That is followed by data collection (64 percent automation potential and 17 percent of time spent). These activities are common to almost all sectors, ranging from human resources staff recording personnel history to mortgage brokers filling in forms, medical staff compiling patient records, and accounting staff processing payments. These are not just entry-level or low-wage jobs; people whose annual incomes exceed $200,000 spend some 31 percent of their time doing those things as well.

[47] Melia Robinson, "This robot-powered burger joint could put fast food workers out of a job," *Business Insider UK*, June 30, 2016.

Exhibit 9

Technical potential for automation across sectors varies depending on mix of activity types



SOURCE: US Bureau of Labor Statistics; McKinsey Global Institute analysis

Companies have long automated activities such as administering procurement, processing payrolls, calculating material-resource needs, generating invoices, and using bar codes to track flows of materials. But as technology progresses, computers are helping increase the scale and quality of these activities. For example, a number of companies now offer solutions that automate entering paper and PDF invoices into computer systems or even processing loan applications. "Robotic process automation" systems use software to automate well-defined data transactions currently performed by many workers.

Financial services and insurance provide one example of this phenomenon. The world of finance relies on knowledge work, not physical work: stock traders and investment bankers live off their wits. Yet about 50 percent of the overall time of the workforce in finance and insurance is devoted to collecting and processing data, where the potential for automation is high. Insurance sales agents spend considerable time gathering customer or product information, as do underwriters on verifying the accuracy of records. Securities and financial sales agents prepare sales or other contracts. Bank tellers verify the accuracy of financial data. As a result, the financial and insurance sector has the potential to automate activities taking up 43 percent of its workers' time.

Performing physical activities and operating machinery in unpredictable environments

In creating our high-level groupings of activities, we divided the performance of physical activities and operation of machinery into two distinct categories depending on the environment or setting in which the activity takes place. As we have seen, carrying out this type of physical activity in a predictable setting has a rote quality to it, and the technical potential to automate is accordingly high, at 81 percent. When the environment or setting is unpredictable, however, the automation potential is much lower, at 26 percent.

Physical activities in an unpredictable environment make up a high proportion of the work in sectors such as forestry and construction. Examples include operating a crane on a construction site, providing medical care as a first responder, collecting trash in public areas, setting up classroom materials and equipment, and making beds in hotel rooms. The environment in these examples is not stable and can change in unpredictable ways. Carrying out these activities thus requires a high degree of flexibility, which makes them harder to automate. For example, people in public areas do not always drop trash in the same place, and while sometimes they might drop paper, at other times they leave plastic bottles or soda cans.

Interfacing with stakeholders

Across sectors of the economy, especially in services, workers interface on a regular basis with a wide range of stakeholders—customers, patrons, or visitors. Greeting them, for example in a retail store, explaining technical product details or service information to customers, including from a call center, responding to complaints and questions, scheduling appointments, or providing advice are just some of the numerous types of interactions that take can place with stakeholders. These types of activity for now have a relatively low potential for automation based on currently demonstrated technologies, just 20 percent. Social and emotional responses are important for these tasks, as are linguistic and cognitive capabilities such as logical reasoning and problem solving.

Applying expertise to decision making, planning, and creative tasks

Even where computers perform above human levels in some well-defined activities such as optimizing trucking routes, humans—for now—still need to determine the goals, interpret the results, or provide commonsense checks for solutions. Activities that require application of decision making, planning, and creativity account for 14 percent, about one-seventh, of the total time spent working in the United States, but they have relatively low automation potential, at just 18 percent, based on adapting currently demonstrated technologies. These activities can be as varied as coding software or creating a menu, developing marketing plans, or writing promotional materials. They are common in fields such as education, human resources, and finance, and considerable amounts of time spent on them in the US economy involve evaluating students' work, coordinating operational activities, and examining financial records or processes.

Managing and developing others

The category of activities we describe as managing and developing others has the lowest automation potential. Only about 7 percent of time in the workplace is spent on these activities, and the potential to automate them is low, about 9 percent. Chief executive officers and senior managers spend a significant proportion of their time engaged in such activities, which brings down their overall automation potential; about 25 percent of a CEO's daily activities could be automated using currently demonstrated technology, but that mainly represents data collection and analysis, rather than talent management.

Among the sectors, education is among the least susceptible to automation, at least for now, with an automation potential of 27 percent. To be sure, digital technology is transforming the field, as can be seen from the myriad classes and learning vehicles available online. Yet the essence of teaching is deep expertise and experience, and complex interactions with other people. Together, those two categories—the least automatable of the seven identified in Exhibit 6—account for about half of the activities in the education sector.

ASSESSING THE AUTOMATION POTENTIAL OF THE GLOBAL ECONOMY

We began our research into automation potential by focusing on sectors of the US economy, to establish the methodological framework that underpins our research. We then broadened the analysis to a total of 46 countries, using comparable national and international data, where available, including wage data from foreign direct investment sources. Details of our international methodology are in the technical appendix.

Overall, currently demonstrated automation technology has the potential to affect activities associated with 41 to 56 percent of global wages depending on country (Exhibit 10). This amounts to about $14.6 trillion in wages and the equivalent of 1.2 billion workers. As we will see in Chapter 4, the actual deployment of automation could vary widely from country to country, depending on a number of factors including the level of wages and the cost of deploying solutions.

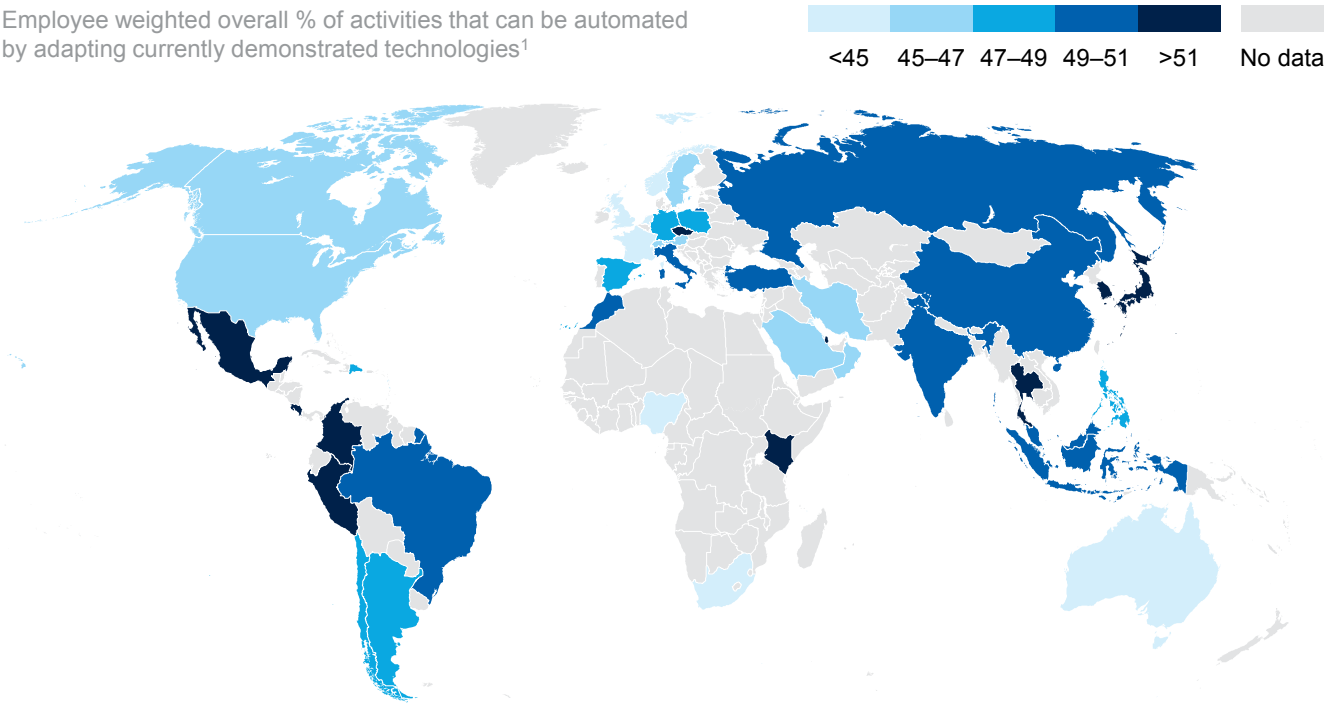
The key differences in the total wages associated with technical automation potential among countries results from differences in the mix of sectors within each economy, the mix of occupations within sectors, and wage levels.

In terms of total wages associated with technically automatable activities, the potential is concentrated globally in China, India, Japan, the United States, and the five largest European Union countries—France, Germany, Italy, Spain, and the United Kingdom. These are the countries with a combination of the largest labor forces or higher wages.

Exhibit 10

The technical automation potential of the global economy is significant, although there is some variation among countries

Employee weighted overall % of activities that can be automated by adapting currently demonstrated technologies[1]



1 Pakistan, Bangladesh, Vietnam, and Iran are largest countries by population not included.

SOURCE: Oxford Economic Forecasts; Emsi database; US Bureau of Labor Statistics; McKinsey Global Institute analysis

Automation potential is concentrated in China, India, Japan, the United States, and the largest European Union nations

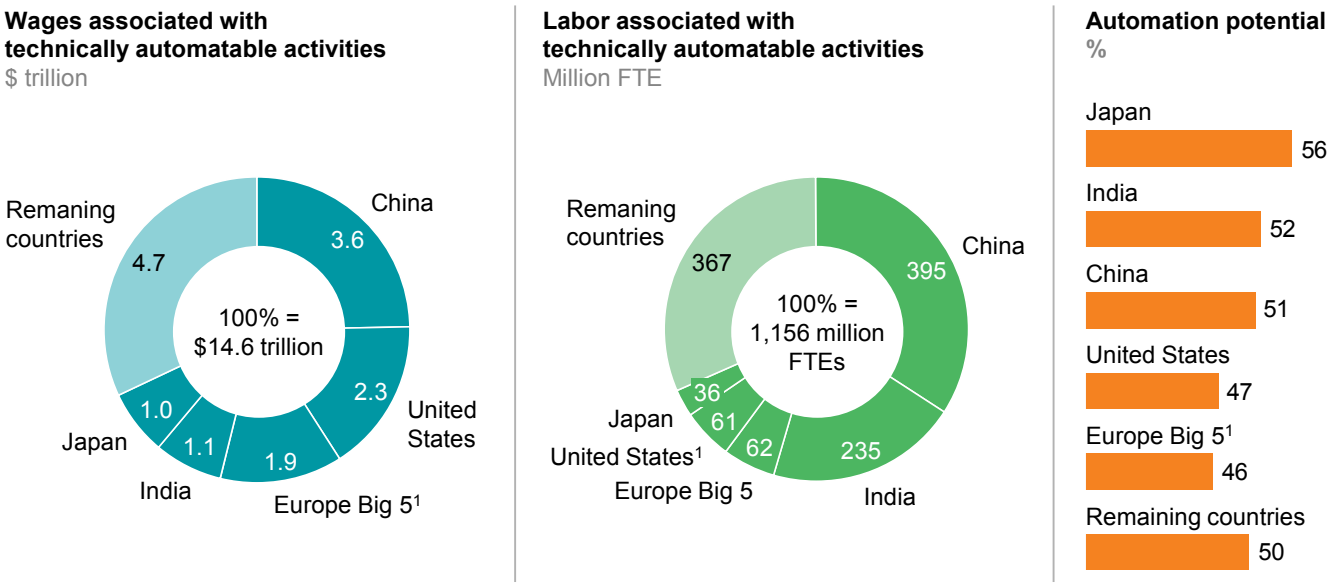
More than half the wages and almost two-thirds of the total number of workers associated with technically automatable activities are in just four countries—China, India, Japan, and the United States. These four together account for about $8 trillion of the wages and more than 700 million employees of the global total potentially affected. In the five largest European Union economies—France, Germany, Italy, Spain, and the United Kingdom—more than 60 million workers and $1.9 trillion in wages are associated with technically automatable activities (Exhibit 11).

The largest amount of employment associated with technically automatable activities is in China and India, because of the relative sizes of their labor force. Technically automatable activities make up the equivalent of more than 600 million full-time workers in the two countries together. In terms of wages associated with technically automatable activities, however, the United States is closer to China's level ($2.3 trillion in the United States vs. $3.6 trillion in China) because of higher wage levels.

Exhibit 11

Technical automation potential is concentrated in countries with the largest populations and/or high wages

Potential impact due to automation, adapting currently demonstrated technology (46 countries)



1 France, Germany, Italy, Spain, and the United Kingdom.
NOTE: Numbers may not sum due to rounding.

SOURCE: Oxford Economic Forecasts; Emsi database; US Bureau of Labor Statistics; McKinsey Global Institute analysis

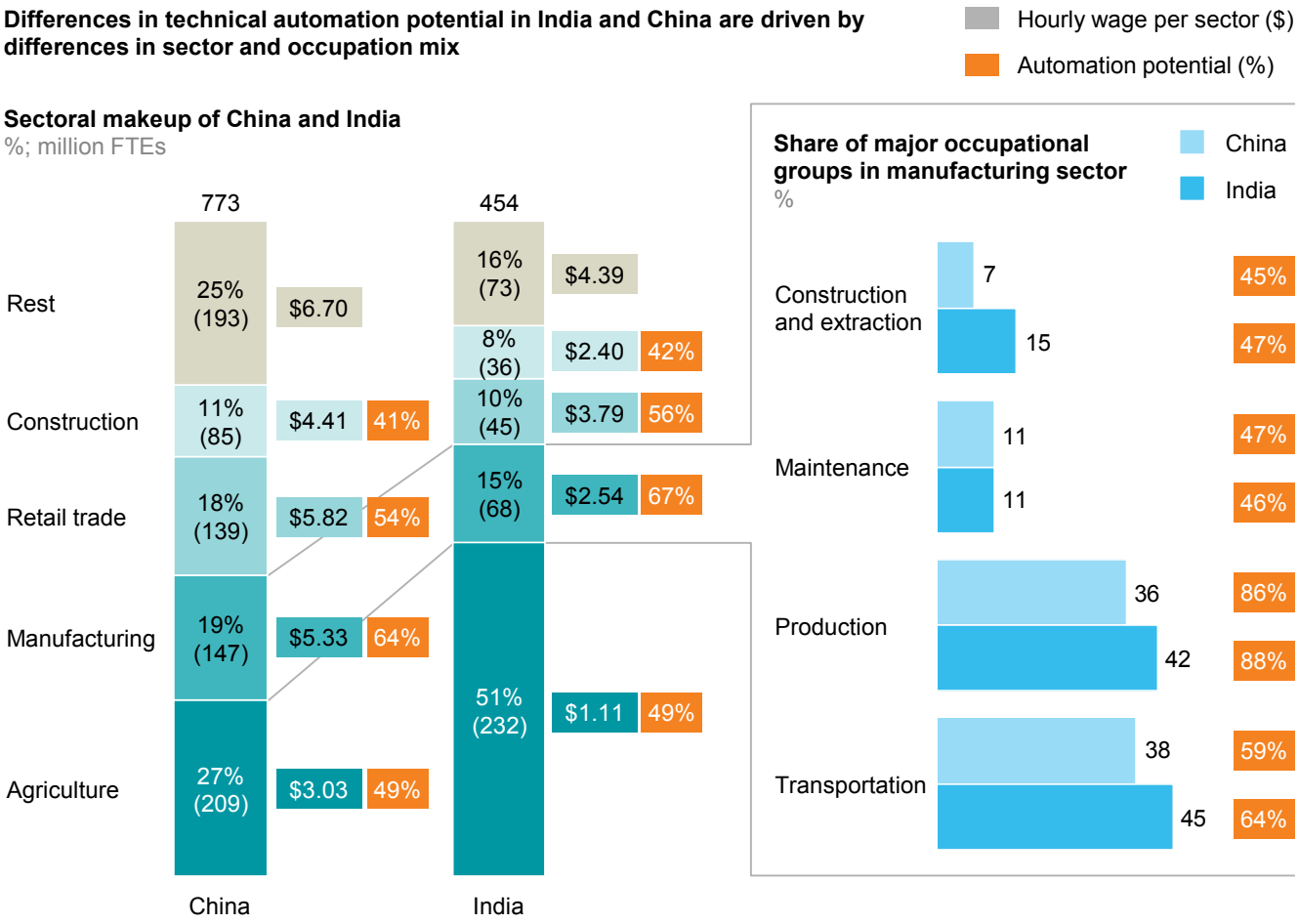
Differences and similarities in automation potential globally

Our analysis of the technical automation potential of the global economy shows that there is a range among countries of about 15 percentage points. Two factors explain this range. The first is the sectoral makeup of each economy. That is, the proportion of a national economy that is in sectors such as manufacturing or accommodation and food services, which both have relatively high automation potential, compared with the proportion in sectors with lower automation potential, such as education, management, and health care. The second factor is the occupational makeup of sectors in different countries. That is, to what extent workers in these sectors are engaged in job titles with high automation potential such as manufacturing production, and those in job titles with a lower automation potential such as management and administration. This weighting changes the automation potential of a sector depending on the country.

Two examples illustrate these differences. The first is China and India (Exhibit 12). With the world's largest workforces, they have similar automation potential and dynamics overall: both have technical automation potential of 50 percent. They have similar top sectors, including agriculture, manufacturing, retail, construction, and transportation and warehousing, and the automation potential within each sector is very similar. Manufacturing and retail play a larger role in China than India, whereas agriculture accounts for a significantly greater share of hours worked than in India than in China as a percentage of the total. Within the sectors, the essential differences result from varying types of job families. For example, India has more welders and sewing machine operators engaged in manufacturing production than China, and both of these job families have a higher automation potential than many other types of jobs, such as managing and developing people, and specialized expert technicians. At the same time, India has a lower proportion of jobs requiring interactions with stakeholders and managing and developing people, activities with low automation potential.

Exhibit 12

Differences in technical automation potential in India and China are driven by differences in sector and occupation mix



NOTE: Numbers may not sum due to rounding.

SOURCE: US Bureau of Labor Statistics; McKinsey Global Institute analysis

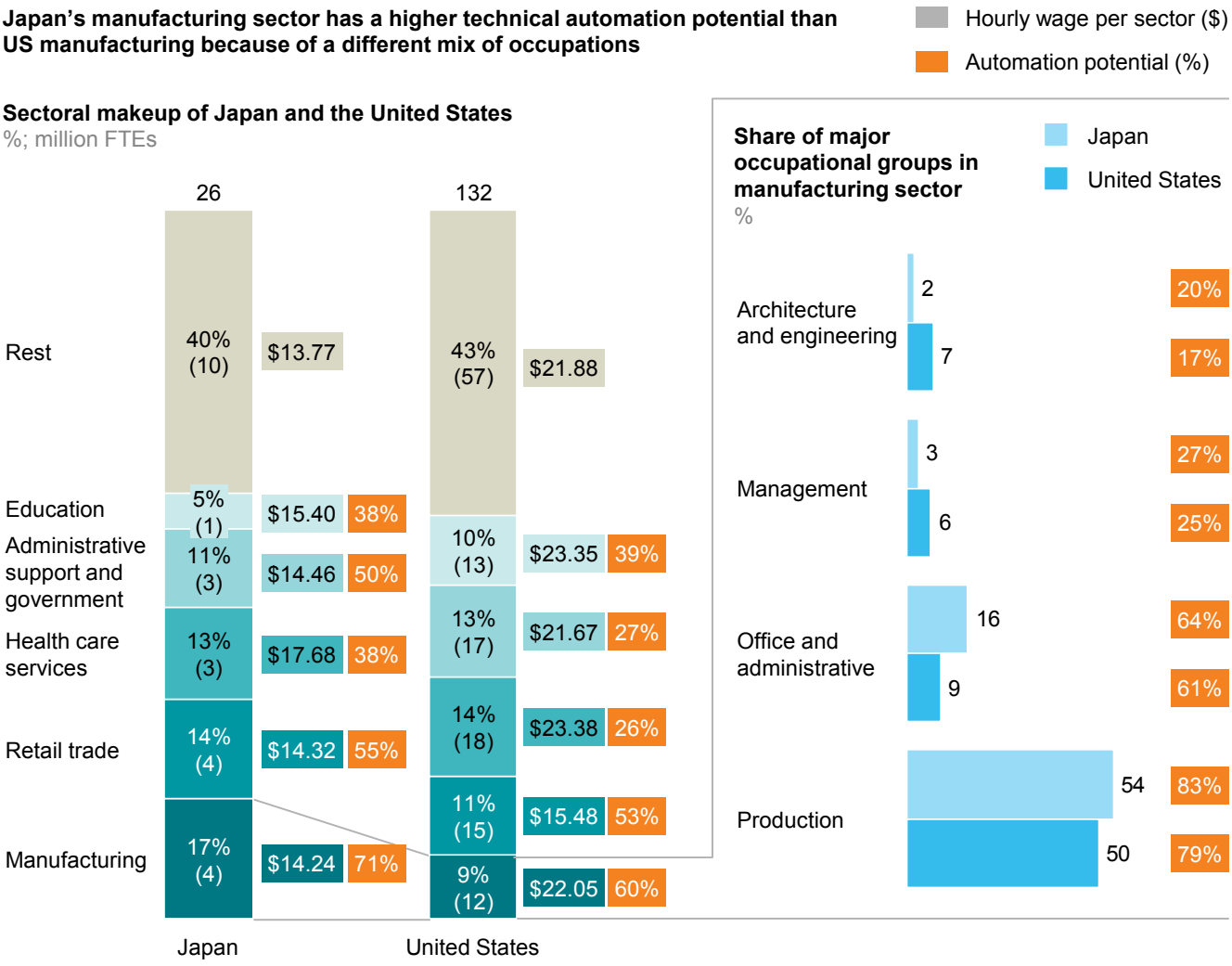
The second example highlights differences between Japan and the United States (Exhibit 13). Japan overall has an automation potential of 55 percent of hours worked, compared with 46 percent in the United States. This difference is primarily due to a different sectoral mix in the two economies, and within those sectors, a different weighting of jobs with larger or smaller automation potential. For example, the automation potential of Japan's manufacturing sector is particularly high, at 71 percent (compared with 60 percent in the United States). Japanese manufacturing has a slightly larger concentration of work hours in production jobs (54 percent of hours vs. 50 percent) and office and administrative support jobs (16 percent vs. 9 percent). Both of these job titles comprise activities with a relatively high automation potential. By comparison, the United States has a higher proportion of work hours in management, architecture, and engineering jobs, which have a lower automation potential since they require application of specific expertise such as high-value engineering, which computers and robots currently are not able to do. These differences outweigh the higher level of wages in the United States than Japan, which affect the business case for automation.

Similar differences exist among countries globally, for example, between Argentina and Brazil, France and Germany, or Kenya, Nigeria, and South Africa. A detailed look at all 46 countries we have examined is available online.[48]

[48] The data visualization can be found on the McKinsey Global Institute public site at tableau.com: **http://public.tableau.com/profile/mckinsey.analytics#!/**

Exhibit 13

Japan's manufacturing sector has a higher technical automation potential than US manufacturing because of a different mix of occupations



NOTE: Numbers may not sum due to rounding.

SOURCE: US Bureau of Labor Statistics; McKinsey Global Institute analysis

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The technical potential to automate work activities in the global economy by adapting currently demonstrated technologies is already close to 50 percent, thanks to rapid advances in automation technologies. That does not mean automation will occur overnight, however, since technical potential is only one of several factors that will eventually lead to automation adoption in the workplace. Only a tiny fraction of entire occupations could be automated with current technologies, but activities across a wide spectrum are susceptible, especially those involving predictable physical activities, data processing, and data collection. What is the outlook for the development of these capabilities? How rapidly could technical potential become workplace adoption? And what would the workplace then look like? In the following chapters, we model some ways automation could arrive in the workplace and lay out timeline scenarios for its actual adoption across the world.

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3. FIVE CASE STUDIES

Our analysis of automation potential inevitably raises questions about the practical effect on workplaces and on the people who work in them. What exactly will change, and how? To develop a vision of automation as it could be applied in the workplace, we have created hypothetical case studies across different industries that suggest how automation could affect specific processes. In this chapter, we outline five of these cases by way of example. The five are from highly varied sectors and involve a broad range of activities across various industry sectors and physical settings: a hospital emergency department, aircraft maintenance, an oil and gas control room, a grocery store, and mortgage brokering.

For all their differences, our case studies also have several essential elements in common. First is the changing nature of work itself, which will likely affect all workers at all skill levels. There will be less routine and repetitive work based on rules-based activities, because this can be automated across many occupations and industries. This in turn will mean many workers may need to acquire new skills. The workplace will become ever more a place where humans and technology interact productively. A major part of most human jobs will involve working together with artificial intelligence, robotics, and other technologies. Automation will affect more than distinct work activities: processes and procedures will also likely have to adapt, too. This in turn will have profound implications for how the workplace is structured and organized.

A second essential element of automation in the workplace will be its impact on business economics. Advances in automation technologies are often depicted simplistically as robots replacing humans. In fact, in evaluating the economics of our case studies, we see that automation's effects are twofold. While it will result in some degree of labor substitution in all five of our case studies, it will also drive significant performance and quality gains in four of the five and, in one of these cases—the oil and gas control room—these performance improvements far outweigh the gains from labor substitution. These improvements are the result of automated systems carrying out a range of activities better than human workers, and include eliminating waste, improving efficiencies, heightening safety, and enhancing quality. As a rule of thumb, capital-intensive industries tend to accrue automation benefits mostly through performance gains, as capital is better utilized, while labor-intensive sectors tend to benefit more from labor substitution. Together they provide a strong rationale for the deployment of automation technology.

The third essential element is that the business case for automation is often strong. The relative cost of automation is likely to be modest compared with the value it can create. The types and sizes of investment needed to automate will differ by industry and sector. For example, industries with high capital intensity that require substantial hardware solutions to automate and are subject to heavy safety regulation will see longer lags between the time of investment and the benefits than sectors where automation will be mostly software-based and less capital-intensive. For the former, this will mean a longer journey to breakeven on automation investment. However, our analysis suggests that the business case is compelling regardless of the degree of capital intensity: the run-rate benefits of investment in automation in our case studies are between three and 11 times the costs of that investment.

These case studies are not precise projections. The vision of the future they provide is based on the hypotheses of industry experts about how these processes could be transformed by automation. While these case studies are partly anecdotal, we nonetheless believe they are a useful exercise that could indicate key benefits and challenges related to developing and deploying automation technologies in various sectors, as well as providing a vision of how automation could actually transform the workplace.

For all five cases, we outline two scenarios: an "interim" future state as automation technology is deployed in current processes and structures, and a "provocative" future state in which we envisage automation being used in a changed structure or process environment that is tailored to maximize its advantages. We also outline some of the likely barriers to automation deployment in each of the cases, including legal and policy obstacles, organizational impediments to change, difficulties in integrating technology, economic viability, and human reluctance to accept technology solutions in certain situations.

IN A HOSPITAL EMERGENCY DEPARTMENT, LESS WAITING FOR BETTER DIAGNOSES AND TREATMENT

Two common characteristics of many hospital emergency departments today are their high level of human interaction and long patient waiting times; in the United States it is rare to be discharged in less than two hours on average.[49] Automation has the potential to reduce those waits and increase productivity, as doctors and nurses focus more effectively on better outcomes, and machines take on routine activities such as registration, checkout, and dispensing of prescriptions (see illustration, "Hypothetical future state of a highly automated emergency department"). Predictive health care using sensing wearables to check vital medical signs and remote diagnostics could cut patient waiting times. For hospitals, automation could streamline billing and other administrative activities.

To achieve such outcomes, hospitals will need to make significant investment in automation technology, along with time and capital to train staff. They will also need to redesign process workflow. Doctors and nurses will have to become comfortable working closely with and trusting automated systems. Safety and liability are significant challenges in a sector where malpractice suits are common; in the United States, about $3.6 billion was paid out in malpractice suits in 2014, and artificial intelligence companies could find themselves on the receiving end.[50] Stringent privacy regulations will need to be safeguarded. The emergency room is also a place where human unease with machines could be strong: people who come to hospitals for medical emergencies usually want and need to interact with qualified humans and may not feel comfortable with machines, however medically competent.[51]

In emergency departments in the United States today, about 80 to 85 percent of the patients are walk-ins, and about the same percentage of the total are treated and sent home usually with prescribed medicines.[52] Patients interact with a range of workers. First are the medical secretaries who enter and validate patient information. Triage nurses check vital signs, request laboratory tests or imaging, and decide to discharge or refer a patient to see a doctor. Doctors examining a patient prescribe medicines and decide to discharge, admit to hospital, or refer the patient to a specialist. Lab technicians conduct tests. At the end of the process, medical secretaries collect payment or compile documentation for an insurance claim.

At least some of these activities could be fully or partially automated. They include the initial work of gathering patients' information, checking vital signs and requesting lab reports. Lab registration and tests are also potentially automatable, as is the end process of payment. Some aspects of a doctor's work in an emergency department are also potentially automatable—not just the data collection that takes up some of a doctor's time, but also some areas of disease diagnosis, and even some aspects of medical procedures and surgery. For example, in radiology, computers are already analyzing X-rays, CT scans, and MRI imagery. Completely automated diagnosis is not likely to happen quickly, partly for reasons of patient acceptance, and partly because of the technical difficulty of integrating data from multiple sources (including natural language understanding, recognizing and processing the patient's emotions) to determine a diagnosis and course of treatment. Automated diagnostic advice is thus likely to augment doctors' decision making before fully automated diagnosis, except perhaps in special instances, such as radiology, or cell pathology (checking for abnormalities through a microscope).

Overall, we calculate that about 30 percent of the benefits of automation in an emergency room would come from performance gains, and 70 percent from labor substitution. Productivity could rise substantially, while the number of full-time equivalents could decline by about half, with the main reductions at the registration desk and in lab testing.

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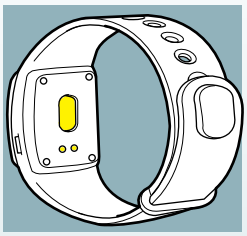
[49] ProPublica lists average waiting and treatment times in US emergency rooms, broken down by state, at https://projects.propublica.org/emergency/. See also Lisa Esposito, "Enduring really long waits at the emergency room," *US News and World Report*, May 8, 2015.

[50] *2015 Medical malpractice payout analysis*, Diederich Healthcare, May 2015.

[51] The unsettling feeling that people may experience when humanoid robots or audiovisual simulations closely resemble humans is known as "uncanny valley," a term coined by a Japanese robotics professor, Masahiro Mori, in a 1970 essay. The eeriness is largely prompted by the machine's appearance, which is realistic but not convincingly so.

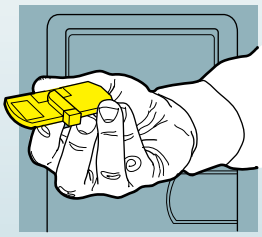
[52] Cheryl Gutherz and Shira Baron, "Why patients with primary care physicians use the emergency department for non-emergency care," *Einstein Journal of Biology and Medicine*, volume 18, number 4, 2001.

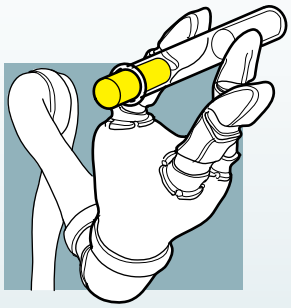
Hypothetical future state of a highly automated emergency department



Patients pre-register by mobile phone. On arrival, they are issued a **wearable monitoring device** that collects vitals

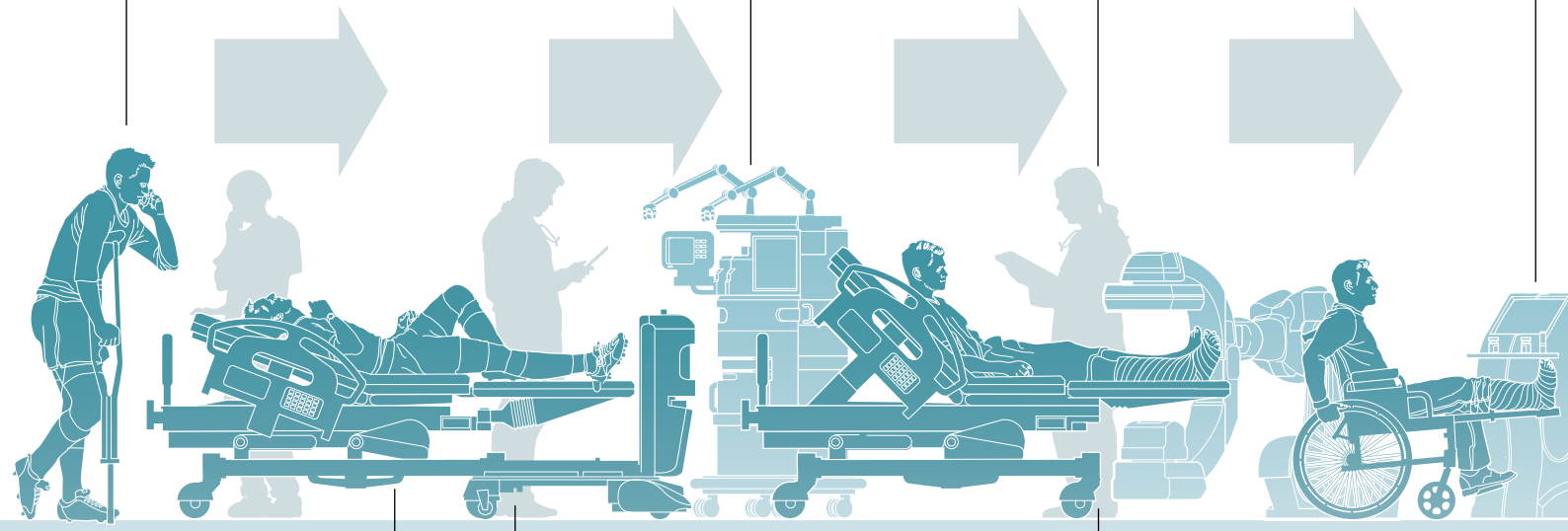
Triage nurses would be aided by automated **fast diagnostics using blood** and auto-generated reports on basis of vitals and tests



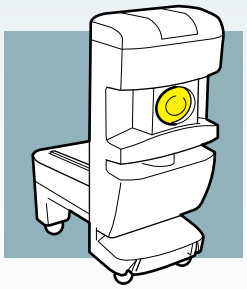


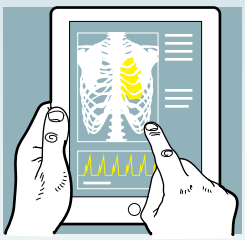
Lab tests would be automated, including report generation, for **improved accuracy**

Fully automated checkout including medicines, billing and issuing reports, or, in the case of hospitalization, bed assignment



Autonomous tugs can pull beds and bring medicines and instruments to the point of care. Drugs are dispensed by automated pharmacy





Algorithms recommend diagnosis and treatment to doctors and nurse practitioners

AI diagnoses and advice on complex and high acuity cases contribute to better outcomes

Potential economic benefits of automation

70% Labor substitution

30% Performance gain

Performance gains

- Increased productivity of nurses and doctors
- Reduced patient waiting time
- Better health care outcomes

11% Relative impact[1]

1 Ratio between additional net impact and operating cost.

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FOR AIRCRAFT MAINTENANCE, AUTOMATION WILL RAISE SAFETY, IMPROVE DEFECT DETECTION, AND REDUCE TIME WASTED ON WALKING AND WAITING

Maintaining a commercial aircraft takes an average of about 8,000 technician hours per plane annually.[53] Technicians conduct visual inspections of the aircraft for signs of physical wear and damage. They also remove and replace parts, conduct a sign-off for quality, and handle administrative tasks, including supplying records to the Federal Aviation Administration where needed. These are jobs that involve spending considerable amounts of time on walking around the aircraft and waiting on parts, planes, or people. They are also dangerous: in 2013, 57 job-related deaths in the United States were in aircraft maintenance.[54]

Automation could have a major beneficial impact on the sector (see illustration, "Hypothetical future state of highly automated aircraft maintenance"). First, removing technicians from fall hazards and fuel tanks would represent a significant improvement in safety. Second, robots equipped with image process algorithms already do a better job than humans at image identification, and deploying them would improve the detection of defects in the aircraft; maintenance errors caused more than one-third of the 179 commercial jet engine accidents between 1988 and 2013.[55] Automated warehouse systems could eliminate about 75 percent of the time wasted by walking around the aircraft, picking up tools and parts, and improved sensors and analytics could raise the proportion of predictive maintenance, which is less costly than reactive maintenance. For maintenance companies, the savings from reduced waste and a move to on-demand maintenance would save costs. Automation could enable experts to monitor all maintenance from a command center, which would reduce variability, and ensure better data collection. Consumers would benefit from these savings if they are passed on in the form of lower flight costs. About half of engine-related delays today are caused by maintenance issues, and so flight delays could also be reduced.[56]

For technicians themselves, automation could change the workplace and their roles. Much of the routine work they carry out, including walking around the plane, moving it, and logging work records, could be automated. Already in an interim phase, remotely controlled robots could crawl through planes and inspect fuel tanks. High-resolution cameras guided by experts could inspect exteriors. Artificial intelligence algorithms could suggest potential problems based on logs even before inspection takes place. In our more advanced automation scenario, small robots could inspect the airframe without moving panels. Automated tugs would move planes, while robotic carts bring and remove parts and tools based on scheduling routines. These and other changes would allow technicians to be more focused on knowledge and handling exceptions, which require greater training.

Overall, we estimate that 35 percent of the value created by automation in aircraft maintenance could come from performance gains, while 65 percent could potentially come from labor substitution.

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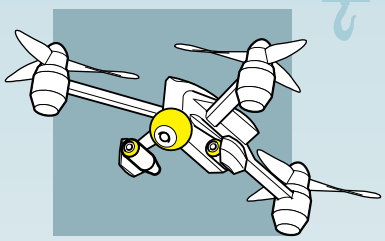
53 Stephen Holloway, *Straight and level: Practical airline economics*, Routledge, 1997.

54 US Bureau of Labor Statistics, 2015.

55 Mary S. Reveley et al., *Causal factors and adverse events of aviation accidents and incidents related to integrated vehicle health management*, National Aeronautics and Space Administration, March 2011.

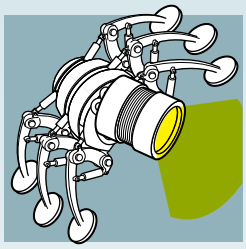
56 Jeffrey O'Brien, "Maintenance: What causes aircraft accidents?" Fiix, May 9, 2012.

Hypothetical future state of highly automated aircraft maintenance



Instead of humans searching for wear and tear visually, **drones inspect exterior**, and tiny insect-inspired robots check airframe without removal of panels

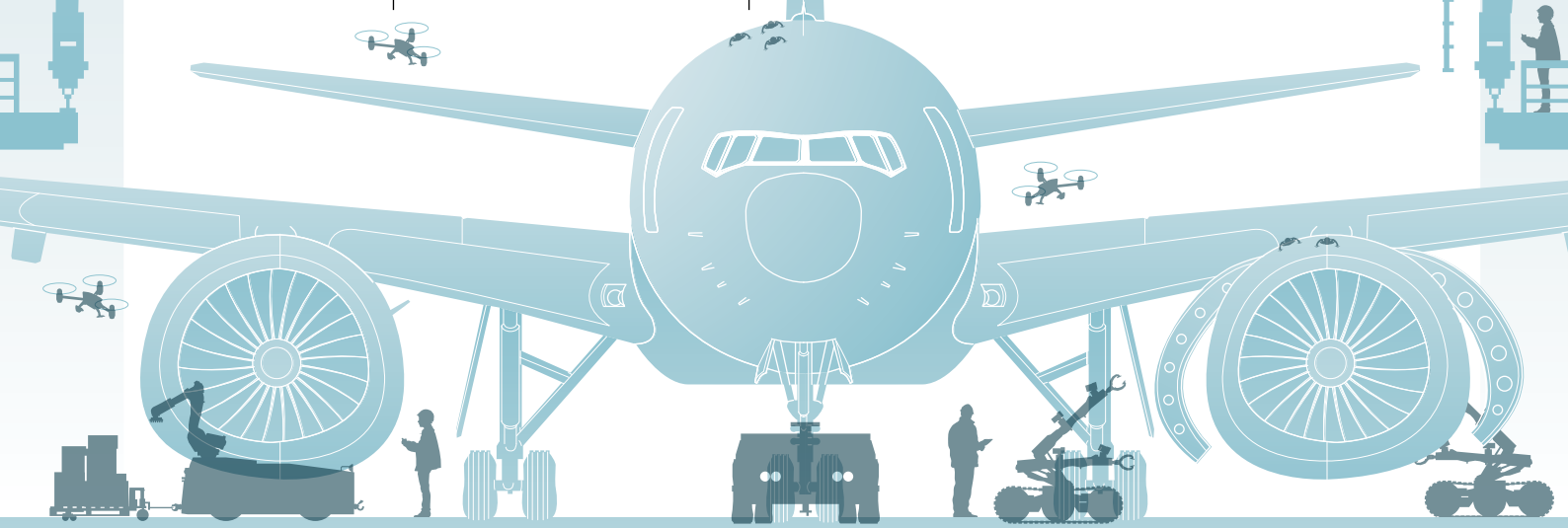
Machine vision to identify many common defects. Predictive maintenance is far less costly than reactive maintenance



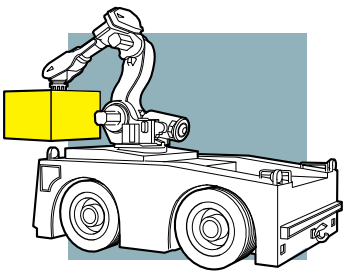
Fewer technicians remain on the maintenance hangar floor, but they spend more time on problem solving, and require more continual training

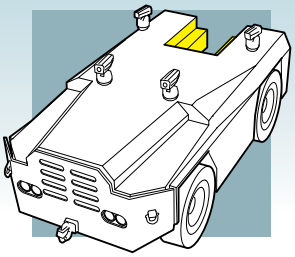
In place of logging inspection status manually, compliance documents are automatically routed to a secure site for easy regulator access

Diagnostic algorithms and inspection robots record all their own compliance information automatically



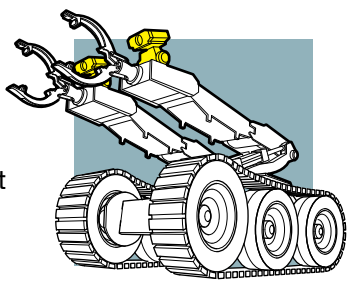
Automated warehouse is linked to procurement department with **robotic part and tool delivery.** Automatic ordering based on forecast demand raises efficiency





Automated tugs rather than technicians move plane in and out of hangar. Less human time spent on tasks that could be done by automation cuts waste

Robots do physical tasks. Humans can avoid danger zones, and parts are installed faster and with less variability



Potential economic benefits of automation

66% Labor substitution

34% Performance gain

Performance gains

- Improved safety
- Better defect detection
- Predictive maintenance
- Elimination of time wasting

25% Relative impact[1]

1 Ratio between additional net impact and operating cost.

McKinsey&Company

IN AN OIL AND GAS CONTROL ROOM, PREDICTIVE MAINTENANCE AND OTHER ADVANCES COULD BRING SIGNIFICANT PERFORMANCE GAINS

Most of the gains of automation in oil and gas control rooms are likely to come from higher productivity and safety (see illustration, "Hypothetical future state of automation in oil and gas operations"). A control room is an operations center that monitors and controls upstream exploration and drilling operations. For now, key roles in the oil and gas sector are divided between onshore and offshore facilities, with operations and maintenance on an offshore rig largely overseen and carried out by managers and workers on the rig, while teams of petroleum and other engineers provide technical support and coordinate activities from headquarters onshore. Offshore work can be a dangerous business: the job-related fatality rate of people working in extraction operations in 2013 was four times the average for the US economy.[57] The performance and training of offshore operators vary, and errors are sometimes made, including ones with severe consequences.

Automation technologies can considerably raise the performance of control rooms by removing operators from environments that are hazardous and expensive to maintain and by capturing data that can be used for predictive and preventive maintenance and operational best practice. Centralizing expertise in an onshore location can improve strategy planning and the effectiveness of event responses. In our more futuristic scenario, permanent seafloor robots could undertake repairs or conduct additive manufacturing, while 3D printers on a surface vessel could print out replacement parts as needed. Robots would conduct standard maintenance, and operating algorithms developed using historical logs could deliver more efficient operations and greater safety.

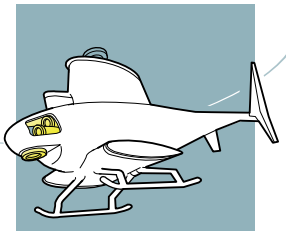
The advantages of automation in this case include better personnel safety, greater efficiency, higher throughput, improved agility, and cost reductions from relocating operators from remote sites to centralized offices. Improved sensors for remote operations and analytics can enable predictive maintenance, which is just one-quarter the cost of reactive maintenance.[58]

Overall, we estimate that 80 percent of the value created from automation in oil and gas control rooms would come from performance gains, with the rest from labor substitution. To reap such gains will require the integration of technologies so that cognitive, sensory perception, and physical capabilities can be deployed on site. Data scientists, engineers, and developers will be needed to develop algorithms that optimize remote management.

[57] *Occupational fatalities during the oil and gas boom—United States, 2003–2013*, Morbidity and Mortality Weekly Report, Centers for Disease Control and Prevention, May 29, 2015.

[58] Elly Earls, "Staying one step ahead with predictive maintenance technology," Mining-technology.com, October 15, 2013.

Hypothetical future state of automation in oil and gas operations



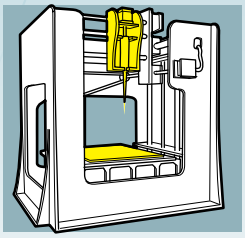
Robots perform predictive maintenance offshore and **human operators are reduced** from the hazardous environment

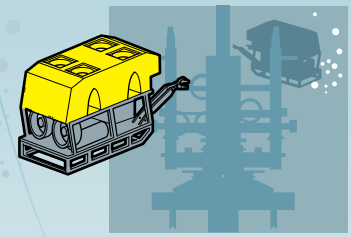
With **fewer offshore people to coordinate**, onshore operations and maintenance are streamlined

Engineers onshore focus on innovation and efficiency, designing modular equipment with maintenance routines for robots

Petroleum engineers are now joined by programmers onshore who work to **optimize throughput**

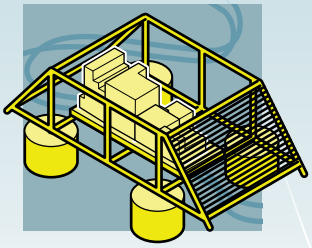
Offshore surface vessel **3D prints components of subsea factories** for robot vehicle installation to equipment





Offshore **seafloor robots** operate, modify, and install small parts in dangerous areas previously serviced by human divers

Subsea factories act autonomously for standard and safety-oriented operations controlling flow and limiting accidents



Potential economic benefits of automation

15% Labor substitution

85% Performance gain

Performance gains

- Better safety, as people removed
- Faster decision-making through global control room
- Predictive maintenance saves costs

17% Relative impact[1]

1 Ratio between additional net impact and operating cost.

McKinsey&Company

AT A GROCERY STORE, IMPROVED CUSTOMER EXPERIENCE AND HIGHER PRODUCTIVITY, AS THE NEED FOR HUMAN STAFF DECLINES

Imagine walking into a grocery store and being greeted by name, courtesy of facial recognition software. Thus begins a highly personalized shopping experience that is faster, more tailored to your preferences, and more convenient than shopping today. If you cannot find what you are looking for, you provide instant feedback. You might use personalized coupons on your mobile device. Once you have finished your selection, an automated back-room service sends out your goods, or a drone drops them off at your home. Best of all, there is no line for payment because there is no physical checkout. The store senses what goods you have with you when you walk out of the store, and payment is accurately and automatically deducted from your preferred account (see illustration, "Hypothetical future state of automation in a grocery store").

We are not all that far from such a scenario today. Stores still have physical shelves, but self-checkout kiosks are becoming commonplace and are a short step from automatic payment and shipping.[59] Robot cleaners and automated storerooms already exist. Augmented virtual reality product views are just a question of time, where consumers will be able to look at displays of goods (probably using special glasses or other technology) to find out more information about the product such as ingredients and nutritional details. One of the biggest overall benefits of automation in retail will be the improved customer experience, as the online and offline shopping experience merges into one, even as it becomes more individualized.

From the employment perspective, our case study suggests that automation in grocery stores could have a significant impact on staffing needs, with a reduction of about 65 percent of hours, mainly for front-end cashiers and people engaged in stocking and cleaning. Some workers could be repurposed toward higher value-added activities such as customer engagement.

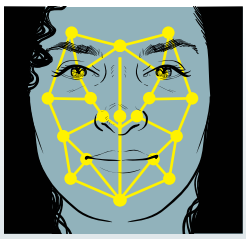
The retail sector overall will face some significant changes. Space productivity will rise, and that in turn will reduce the need for large stores. Smaller stores require less investment; we estimate savings of 60 to 80 percent. Lower inventory and working capital will also be a feature of the new retail business landscape, as the brick-and-click models merge into a seamless whole, and retailers leverage physical stores as distribution centers. Data analytics will enable retailers and manufacturers to customize and target promotions.

Some customers may find marketing use of their personal data, including location-based alerts, overly intrusive. Many jobs in retail are entry-level, low-skill ones, and the elimination of many such positions could cause a public outcry. Training will be essential so that staff can troubleshoot technical and other problems and make recommendations. From a technology perspective, sensory perception will need to be integrated with pattern matching, so that customers are recognized and given relevant recommendations.

While the potential savings from smaller formats, less inventory, and lower payroll could be significant, the slim margins in retailing may mean that only large chains will have the capital needed to make the investment in full automation. Overall, we estimate that the benefits of automation will be three times the cost. Along with health care, this is the lowest ratio of our five case studies. Labor substitution gains in retail accounts for 68 percent of the potential gains, compared with 32 percent from improved performance.

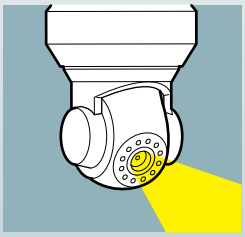
[59] Amazon in December 2016 launched a store without cashiers, Amazon Go. Leena Rao, "Amazon Go debuts as a new grocery store without checkout lines," *Fortune*, December 5, 2016.

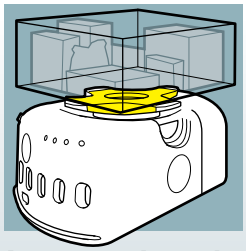
Hypothetical future state of automation in a grocery store



Automatic facial recognition and personalized greeting on **arrival**. Virtual assistants provide directions

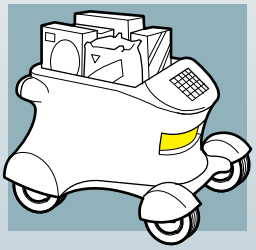
Continuous inventory tracking through sensors and video



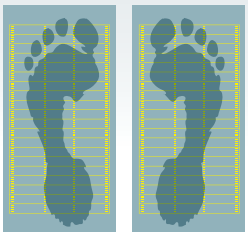


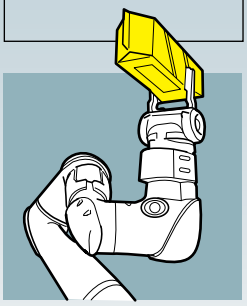
Automated stock room manages inventory and prepares custom orders, with delivery by autonomous drone or vehicle

No lines and no-stop **checkout**, thanks to automatic payment and shipping. Just head home, and the groceries will follow right behind you



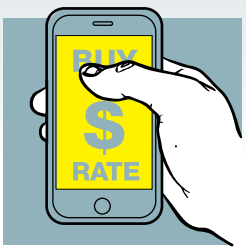
The **footprint** of the average US supermarket is the size of two football fields. Automated stores, without the need to display so much of their wares, would be smaller





An automated shopping cart follows you around. The shelves are monitored and **restocked automatically by robots**

Purchases are made by **mobile phone.** Customers receive personalized mobile coupons, and can give instant feedback



Potential economic benefits of automation

68% Labor substitution

32% Performance gain

Performance gains

- Improved customer experience
- Higher space productivity through backroom automation
- Lower inventory and working capital needs

14% Relative impact[1]

1 Ratio between additional net impact and operating cost.

MORTGAGE APPLICATIONS: SPEEDING UP THE PROCESS, REDUCING DROPOUT RATES, AND RAISING CUSTOMER SATISFACTION

The financial-service industry has been at the forefront of adopting automation technologies for a range of back-office work. This case shows how that degree of automation could reach even higher levels. It focuses on the business of processing mortgage applications, which consists in large part of collecting and processing data, two categories of activity that already have a high automation potential, by adapting currently demonstrated technologies. Our scenarios for automation in this process accordingly correspond to a sharp reduction in the overall required labor hours, of between 55 and 85 percent. The speed with which mortgages are processed could accelerate substantially. For now, it takes an average of 37 days to approve a mortgage application in the United States, of which about 14 to 21 days are spent on the mechanics of application processing.[60] In our interim automation scenario, in which technology is deployed in current processes and structures, this could drop to less than six days. In a more futuristic scenario, in which the processes themselves change, mortgage approvals could come through in less than a day. The shorter turnaround time could improve the dropout rate by possibly 30 percent or more, as many people who apply for mortgages today drop out as a result of the lengthy process.

For mortgage companies, the improvements derived from automated processes could lower default risks and eliminate inconsistencies in processing, thereby reducing the need for human performance management. Automation could also create a potential for partnership between mortgage companies and real estate agents for real-time lead generation, mortgage application, and loan fulfillment. Customer satisfaction could rise as a result of instant pre-approval, hassle-free applications, and much faster turnaround. Moreover, some of the industry's challenges, including human bias in underwriting and the difficulty that underserved borrowers can have in accessing affordable capital, could also be eased by automated processes.

Of our five cases, however, the automation of mortgage applications will potentially weigh most heavily on labor. The vast majority of the impact in this process, about 88 percent, would come from labor substitution gains, compared with just 12 percent from performance gains. Moreover, the business case to move to automation is strong, since the software costs could be relatively low, and wages of loan officers are relatively high, at $35 per hour.[61] The run-rate benefit from automated mortgage origination could be as much as 11 times the cost of automation itself, according to our estimates, easily the highest ratio of our five case studies.

For mortgage brokers, automating and speeding up the approval processes will allow more time on complex tasks such as advising customers or handling exceptions that require human expertise and judgment, as well as additional time to manage unusual applications. That in turn will require more training. Data scientists will also be needed to increase the accuracy of algorithms used in processing, and to integrate platforms and data sources. Nonetheless, there is likely to be considerable restructuring and elimination of redundant positions in the core application processing functions, which could require managing labor issues, including helping to redeploy displaced workers.

To reap the full benefits of automation, the entire mortgage approval process will need to be redesigned and piloted in select branches to ensure all necessary resources are available. There are technological challenges in ensuring end-to-end integration with systems from retail banks and underwriters, such as handling documents, messaging, and conducting risk analysis. However, given the potential cost savings and fairly certain return, financial institutions have an incentive to invest in automation for their mortgage origination activities, much as they have for straight-through processing of other types of transactions.

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[60] Evan Nemeroff, "Survey shows average mortgage closing time hits three-year low," *National Mortgage News*, August 22, 2014.

[61] Occupational Employment Statistics, US Bureau of Labor Statistics, 2014.

No sector of the economy will be immune to automation. While our five hypothetical case studies are not precise predictions about how automation will be deployed in the workplace, they do signal some of the key benefits and challenges to come. Integrating technological capabilities, retraining staff, adjusting processes, and, in some sectors, working out how to make workers and customers comfortable interacting with machines rather than humans, are among the considerable changes that will be required to maximize the benefits from automation. Gains from labor substitution could be significant, but they will vary from sector to sector. Performance gains, in the form of better quality, greater safety, and higher productivity, could also be substantial, to judge by the findings of our case studies. How quickly will any of this happen? In the next chapter, we analyze the factors that will hasten or slow the adoption of automation, and project timelines for its implementation in the global economy.

Fully automated vehicles moving containers at the port of Los Angeles.
© Tim Rue/Bloomberg/Getty Images

4. FACTORS AFFECTING THE PACE AND EXTENT OF AUTOMATION

Automation will be a global force, affecting all countries, all sectors, all jobs, and all work activities. Already today, machines and algorithms are playing a much larger role in the workplace, but how soon will it be before we all feel the impact of automation technologies? Could machines really carry out much or most of the work humans do today—and if so, by when?

In this chapter, we describe factors that can affect the pace and extent to which automation is adopted in the global economy. We also present the results of a model that includes a range of potential scenarios illustrating how the automation of existing work activities could evolve.

FIVE FACTORS INFLUENCING AUTOMATION OF WORK ACTIVITIES

Overall, we have identified five broad factors that can influence the pace and extent of automation of work activities. They are: technical feasibility; the cost of developing and deploying solutions; labor market dynamics; economic benefits; and social and regulatory acceptance.

Technical feasibility

Technology has been automating human activities for centuries, from the printing press to the steam engine and the internet, and fundamentally reshaping the economy in the process. Over the past two centuries, the share of people working on the land in advanced economies has fallen from a majority to a tiny fraction. More recently, the United States and other advanced economies have seen a decline in the share of the workforce engaged in manufacturing. Technological advances require basic scientific research, but in order for these advances to be adopted, they also require engineering solutions, or "applied research." Both take time to develop. There is a lag between a technology being demonstrated, and a viable product being developed using that technology. Orville and Wilbur Wright pioneered flying an aircraft in 1903, for example, but it took 11 more years before the first commercial flight, across Tampa Bay, in Florida, took place, and the true birth of commercial aviation in the United States is usually dated back to 1926, when pioneering operators had to begin complying with federal regulations.[62] There was a similar lag in the development of automobiles, between German engineers Nikolaus Otto, Gottlieb Daimler, and Wilhelm Maybach, patenting the compressed charge, four-cycle engine in the 1870s and production of automobiles on a commercial scale some 15-20 years later. Solutions have to be engineered for specific use cases. While from a "scientific" perspective, a light passenger vehicle is conceptually the same as a tractor-trailer, the engineering required to develop these two solutions has very different specifications and each requires time and energy. Similarly, while you could view predictive maintenance of a complex engineered system such as a power plant and preventive health care for a congestive heart failure patient (predictive maintenance of the "human system") as being conceptually the same problem, actually creating the software and models to prevent a failure in these two systems require quite distinct and considerable engineering efforts.

At times, a paradigm shift is needed in how a new technology should be applied. When steam engines in factories began replacing the water wheel, everything was driven from a central mechanical drive. The first attempts at using electricity tried to duplicate this, but

[62] Ronald E.G. Davis, "The birth of commercial aviation in the United States," *Revue belge de philologie et d'histoire*, volume 78, number 3, 2000.

only really made a difference when people realized it would be more efficient to distribute electrical energy through the building, and have separate electric motors in individual machines, rather than one central motor that distributes mechanical energy.[63]

Today, technological advances in automation abound in areas from physical hardware and robotics to artificial intelligence and software, as we discussed in Chapter 1. Yet much of the innovation that we are seeing, from self-driving cars to digital personal assistants such as Apple's Siri, Amazon's Alexa, and Google Assistant, are still in development—and often imperfect. That means there remains a lot of work to be done by scientists and engineers.[64]

Cost of developing and deploying solutions

The cost of automation technologies will affect when and where they are deployed. The costs of developing and deploying solutions have to be recouped. Even when the technology is purchased from a supplier, the supplier will amortize the development costs into the pricing.

Developing and engineering automation technologies takes capital. Some technologies require substantial physical infrastructure such as tooling and laboratories. But even "virtual" solutions that are based on software require real investments in engineers to create solutions. A decade ago, the largest corporate research and development spending was to be found in automotive and pharmaceutical companies; today, technology companies dominate, with companies including Amazon, Alphabet, Intel, and Microsoft spending more than $10 billion apiece on annual R&D.[65] Hiring talent can also be costly. Google, for example, acquired DeepMind Technologies in 2014, at an estimated price of $500 million. With approximately 75 DeepMind employees at the time of the deal, the price tag was nearly $7 million per employee. This is in line with other estimates by experts, who say that "aqui-hires" of cutting-edge AI startups cost around $5 million to $10 million.[66]

Deploying automation technologies also incurs costs. For physical technologies, these are real capital expenditures. Industrial robots cost from tens of thousands to millions of dollars. Replacing an ordinary heavy truck with a self-driving truck requires an expenditure of capital. And the self-driving truck will likely be more expensive than the truck it replaces, at least when the technology is first released.

These deployment costs are lower for software-based solutions, especially when delivered remotely through the cloud, and where the software is sold as a service, thereby turning capital expenditure into operating expenditure. But "the cloud" has a real physical instantiation as data centers and networks, and they in turn represent costs. Moreover, deployment of a software (or hardware) solution can almost never be done without significant implementation services, such as the costs of customizing the software for an individual organization, changing the processes within an organization, and training staff. For enterprise software, the associated implementation services often cost several times the costs of the software itself. All these costs affect the business cases for where and when automation is adopted.

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63 Nicholas Carr, *The big switch: Rewiring the world from Edison to Google*, W. W. Norton, 2008.

64 For recent research on the modeling of enterprise 2.0 adoption, see Jacques Bughin, "Taking the measure of the networked enterprise," *McKinsey Quarterly*, October 2015, and Martin Harrysson, Detlef Schoder, and Asin Tavakoli, "The evolution of social technologies," *McKinsey Quarterly*, June 2016.

65 Justin Fox, "The big spenders on R&D," *Bloomberg News*, April 29, 2016.

66 *The age of analytics: Competing in a data-driven world*, McKinsey Global Institute, December 2016.

Labor market dynamics

The labor costs associated with work activities that could potentially be automated are another factor that will affect the pace and extent of automation. These costs are affected by the complex dynamics of labor markets.

Even for the same activity, for example, entering data into a financial system, there is a wide range of wages paid, across different positions—from accounting clerks to chief financial officers—and in different companies, for example a small, family-owned business compared with a Global 50 corporation. Wage rates also vary by geography.

Labor supply is determined by demographics, with the share of the working-age population potentially declining in many countries in coming decades. But it also varies in terms of skills, which are affected both by intrinsic talents of individual human beings, as well as by education and training that people receive. People can learn new skills but it takes time and money (see Box 3, "Technological change and skills")

Labor markets are dynamic systems. Supply, demand, and wages all vary over time. If automation frees up human capital, then supply will increase, which could be redeployed into other positions if the demand exists. But there could be a skills mismatch, which will require time and training, delaying redeployment. There could also be information asymmetries, which digital labor markets could help address.[67]

Box 3. Technological change and skills

Economists who study the impact of technological innovation on the workforce have noted varying effects on workers at different skill levels, depending on the time period.[1] In the 19th century, for example, technological changes raised the productivity of lower-skill workers and created new opportunities for them, at times replacing the craftsmanship of higher-skill artisans. This so-called unskill-biased technical change reduced the value of some high-skill workers even as it boosted lower-skill ones.

With the advent of information technology and the internet, the reverse has happened: the productivity of higher-skill workers, especially those engaged in abstract thinking, or with creative and problem-solving skills, has increased, while the relative demand for lower-skill workers has not. This phenomenon of skill-biased technical change is manifested in a number of ways. In advanced economies, median income households have been receiving a lower share of the total wage share of GDP, in part because demand for less-skilled workers has dropped, even as demand for high-skill labor has risen.[2] In 1981, college-educated workers in the United States earned a 48 percent wage premium over high school graduates. By 2005, that premium had risen to 97 percent—in other words, an American college graduate earns almost twice as much as a high school graduate.[3]

What will the spread of automation mean for workers at different skill levels? Erik Brynjolfsson and Andrew McAfee discuss a new shift to "talent-biased technical change" which has created very high demand for superstars such as experts in artificial intelligence or data scientists.[4] Our analysis suggests that all workers at all skill levels have the potential to be affected at least partially by automation based on currently demonstrated technologies.

1 See David H. Autor, Frank Levy, and Richard J. Murnane, "The skill content of recent technological change: An empirical explanation," *Quarterly Journal of Economics*, November 2003, and Daron Acemoglu and David H. Autor, "Skills, tasks, and technologies: Implications for employment and earnings," in *Handbook of Labor Economics*, volume 4B, David Card and Orley Ashenfelter, eds., Elsevier, 2011.

2 See, for example, *Global wage report 2012/13*, ILO, December 2012; *OECD economic outlook 2012 volume 1*, OECD, June 2012; Andreas Hornstein, Per Krusell, and Giovanni L. Violante, *The effects of technical change on labor market inequalities*, Center for Economic Policy Studies working paper number 113, July 2005.

3 David Autor, "Skills, education, and the rise of earnings inequality among the 'other 99 percent,'" *Science*, volume 344, issue 6186, May 2014.

4 Erik Brynjolfsson and Andrew McAfee, *The second machine age: Work, progress, and prosperity in a time of brilliant technologies*, W. W. Norton & Company, 2014.

Demand is also not static. New types of work activities and jobs are created all the time, even as new technologies come on the market. Bank tellers and ATMs are one example. ATMs were first installed in the United States and other developed economies in the 1970s, and from the mid-1990s, banks rapidly increased their use of ATMs. Contrary to some expectations, their advent actually increased the demand for human tellers, for two reasons. First, ATMs reduced the cost of operating a bank branch, and banks responded by opening more branches. Fewer tellers were needed in each branch, but more branches meant that teller jobs did not disappear. Second, the tasks that ATMs could not do—in particular, developing relationships with clients such as small businesses—became more valuable. For tellers, the nature of their activities changed, with cash handling becoming less important and human interaction more important.[68]

The relative costs of labor vs. automation will affect the pace and extent of adoption. If workers are in abundant supply and significantly less expensive than automation, this could be a decisive argument against it. For example, food service is one activity with a high automation potential based on adapting currently available technologies. However, current wage rates for this activity are among the lowest in the United States, reflecting both the skills required and the size of the available labor supply. Since restaurant employees who cook earn an average of about $10 per hour, a business case based solely on reducing labor costs may be unconvincing.

Economic benefits

The potential economic benefits from automation are not limited to labor cost reductions. As we noted in the case studies in Chapter 3, performance gains include increased profit, increased throughput and productivity, improved safety, and higher quality, which are harder to quantify than labor costs but no less tangible. In our hypothetical look at automation of an oil and gas control room, for example, performance gains accounted for more than three-quarters of the total benefits. There are also indirect benefits, such as wage growth, and automation's potential to create business and economic incentives that drive corporate decision making, and unleash entrepreneurial energy. Automation could also spur policy makers. However, these indirect benefits will have to be netted out against indirect costs caused by automation, such as those associated with labor displacement

Regulatory and social acceptance

Automation faces some significant regulatory and social barriers to implementation. They include safety and liability issues. One accident could trigger stringent regulations. Artificial intelligence used in military robots or autonomous vehicles may have to make judgments that harm people, creating moral controversy. Technology makers could also be exposed to legal product liability if robots malfunction.

Privacy is also a potential barrier, especially in areas where personal data is highly sensitive, such as health care; already, health care IT can struggle to link together different data sets due to mandatory anonymization of data.

From a social perspective, too, automation will need to overcome some barriers. If many workers lose jobs and are unable to find new ones, the social and political pressures against automation could become significant. Humans may not want to adopt new technologies or work with automated products due to fears about job security.

Finally, personal preferences and discomfort with technologies could prevent automation in settings where human relationships are important, such as for caregivers.

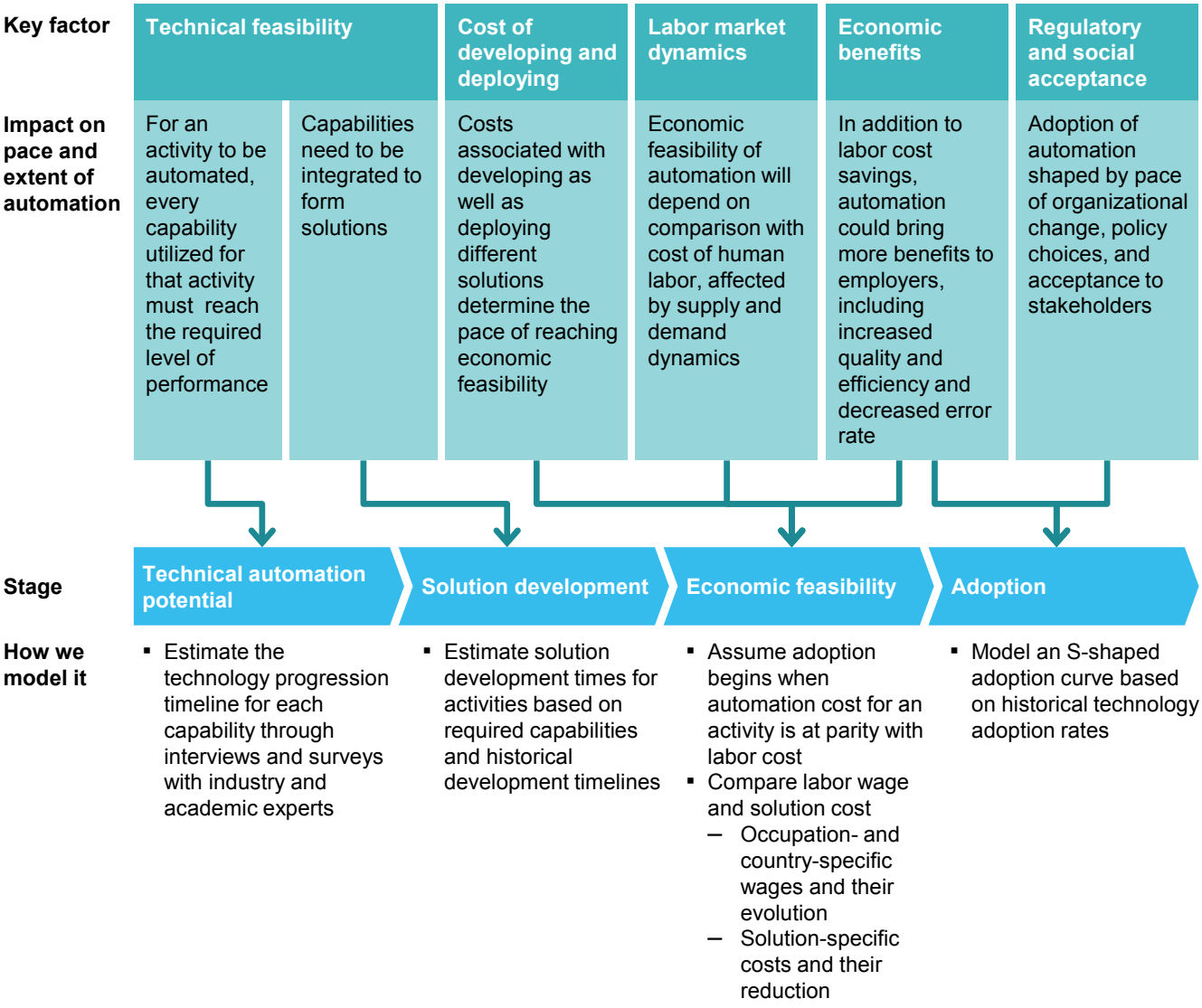
[68] James Bessen, "Toil and technology," *Finance & Development*, volume 52, number 1, March 2015.

MODELING SCENARIOS FOR POTENTIAL PACE AND EXTENT OF ADOPTION

To analyze a range of potential scenarios for the pace at which automation could affect activities across the global economy, we constructed a model that synthesizes the effects of these five factors into four timing stages. We estimate when automation technologies will reach each level of performance across 18 capabilities, the time required to integrate these capabilities into solutions tailored for specific activities, when economic feasibility makes automation attractive, and the time required for adoption and deployment (Exhibit 14). We modeled scenarios incorporating these stages for each individual activity in every occupation for all sectors across 46 countries that account for about 80 percent of the world's workforce.

Exhibit 14

Five factors affect the pace and extent of automation; we model using four stages



NOTE: Economic benefits affect both when adoption will begin and its pace. For determining economic feasibility, we assume that decision-makers discount the uncertain benefits of initial labor cost savings by roughly the same amount as they believe the also uncertain non-labor cost-related benefits will be captured.

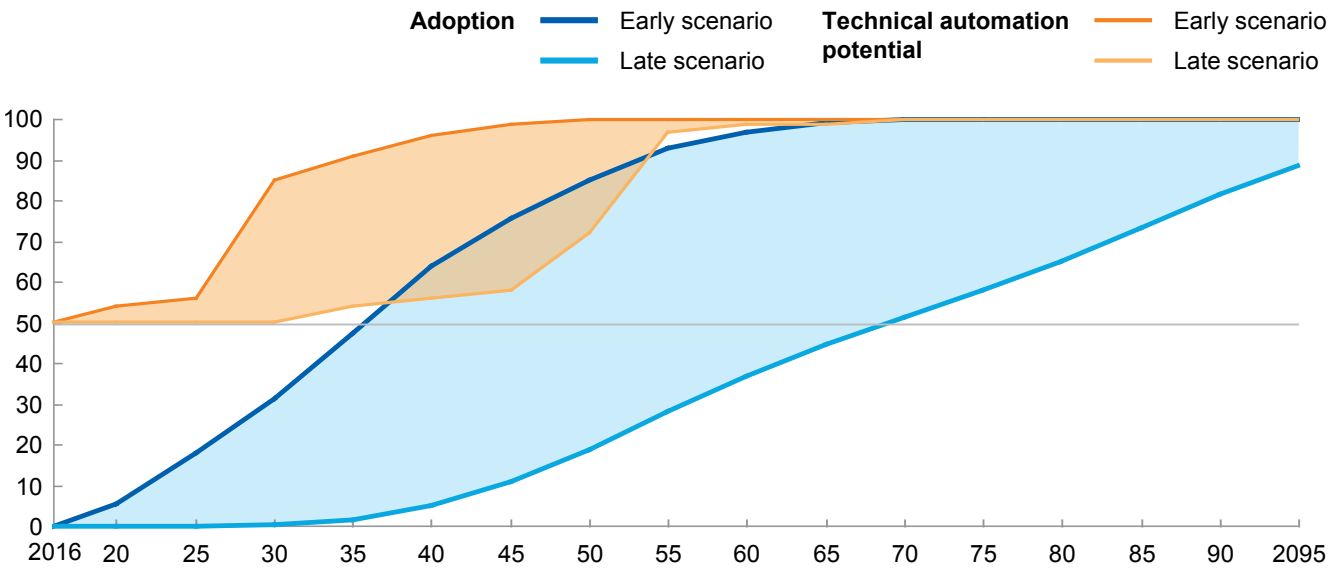
SOURCE: McKinsey Global Institute analysis

The scenarios we have modeled create a time range for the potential pace of automating current work activities. We have created two theoretical bookends, an "earliest" scenario, in which all of the modeling parameters are flexed to the extremes of the set of plausible assumptions that would result in faster automation development and adoption, and a "latest" scenario, in which we flex all of the parameters in the opposite direction. The reality will likely fall somewhere between the two. Modeling all of these factors, the date at which 50 percent of the world's current work activities are automated could be around 2055, but we posit possible scenarios where that level of adoption occurs up to almost 20 years earlier or later. (Exhibit 15).

Exhibit 15

Automation will be a global force, but adoption will take decades and there is significant uncertainty on timing

Time spent on current work activities[1]
%



1 Forty-six countries used in this calculation, representing about 80% of global labor force.

SOURCE: McKinsey Global Institute analysis

We stress that we are not making specific point predictions; we use scenarios to describe the envelope of potential outcomes, and we fully acknowledge the simplification that comes with any modeling exercise. For example, we do not account for all of the dynamics of the labor market described above, including whether wages for specific occupations would decline because displaced workers would increase labor supply.

The model is likely to be precisely wrong but we hope it is directionally right with regard to overall findings. Occupations within sectors with high automation potential today, jobs that involve types of activities that we categorize as easiest to automate, such as physical activities in a predictable environment or data collection and processing, will most likely be among the first to feel the impact of automation. From a geographical perspective, advanced economies are likely to deploy automation ahead of many emerging economies, because of higher wage levels, which make a stronger business case for deployment, as well as the nature of the solutions that will be needed to integrate the technologies into the workplace.

Furthermore, while the macro effects on a nation's entire economy may be quite slow (we model the adoption of automation across several decades), the micro impact on particular work activities, in certain sectors, and in individual countries, could be quite fast, as competitive pressures come together with advances in technological development. That is, for an individual worker who is displaced by automation, or a company whose industry is disrupted by competitors using automation to shift the basis of competition, these effects could occur quickly indeed.

DEVELOPING AUTOMATION CAPABILITIES IS A KEY INITIAL DETERMINANT OF ADOPTION TIMELINES

The deployment of automation in the workplace can begin only when machines have the capabilities required to carry out particular work activities. Technological innovation must first deliver the technical capability before a workplace solution can be developed and deployed.

In Chapter 2, we outlined 18 performance capabilities required to carry out the range of work activities and the current state of the technology for those capabilities as measured against human performance. Along with our assessment of the current state, we developed progression scenarios for each of these capabilities. We did so through surveys of academic and industry experts and through an extrapolation of metrics including recent commercial successes and the historical trajectory of the capabilities, along with a range of other predictors. Details of our methodology can be found in the technical appendix.

While machines can already match median human performance or even exceed the top levels of human performance in some of the 18 capabilities, such as, for example, information retrieval, gross motor skills, and optimization and planning, many other capabilities require more technological development, for example to raise natural language understanding and logical reasoning to a median human level.

Scenarios for achieving higher levels of performance capabilities

Exhibit 16 shows a potential range of time frames for technology to attain the next level of performance for each capability. From a technical standpoint, some of these performance capabilities are quite far advanced, and developing top-quartile human performance may be relatively fast, although there are some significant variations among the different capabilities.

- Sensory perception is already at median human performance. A robot "tongue" can already detect the color index and alcohol content of beer with more than 80 percent accuracy, for example.[69] For tactile perception, which can already exceed top-quartile human performance for several dimensions, key challenges include miniaturizing the size of hardware and adapting the sensors to function in different environments.[70]

- Cognitive capabilities are considerably more varied in their performance compared to humans. Information retrieval, optimization and planning, and recognizing known patterns and categories have already reached the top quartile of human performance, whereas generating novel patterns, creativity, coordination with multiple agents, and logical reasoning and problem solving are still at a relatively early stage. In terms of coordinating with multiple agents, robots already have demonstrated the ability to coordinate with similar types of robots.[71] Their ability to collaborate with humans is still at an early stage. Automated creativity is perhaps the furthest away; computer creativity for now requires human involvement to judge the quality of work or to provide direction.

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[69] Carlos A. Blanco et al., "Beer discrimination using a portable electronic tongue based on screen-printed electrodes," *Journal of Food Engineering*, volume 157, July 2015.

[70] Giorgio Cannata and Marco Maggiali, "Design of a tactile sensor for robot hands," in *Sensors: Focus on tactile, force and stress sensors*, Jose Gerardo Rocha and Senentxu Lanceros-Mendez, eds., InTech, 2008.

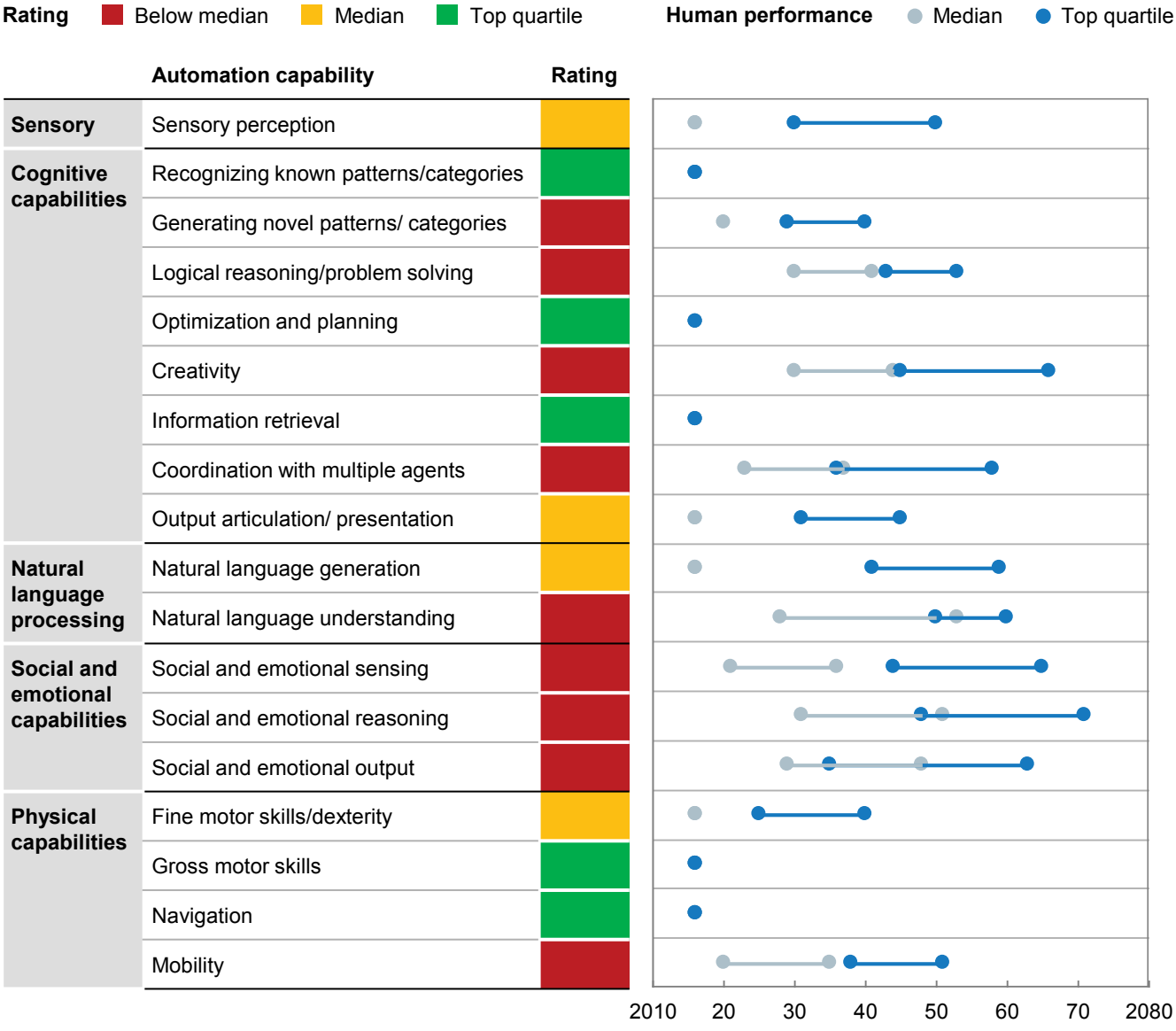
[71] Julia Sklar, "Making robots talk to each other," *MIT Technology Review*, August 2015.

- Social and emotional capabilities for now are below median human performance levels. Despite advances in artificial intelligence, machines still have difficulty identifying social and emotional states (sensing), drawing accurate conclusions about them (reasoning), and responding with emotionally appropriate words or movements to them (output).

- Physical capabilities are already at top-quartile human performance for gross motor skills and navigation, which has enabled wide deployment of robots in industrial automation, military, and defense—and given consumers turn-by-turn navigation apps for their smartphones. For fine motor skills, we estimate that top-quartile performance could be achieved when robotic hands have the same degrees of freedom as human hands. Mobility remains a challenge, especially vertical mobility such as climbing stairs and ladders.

Exhibit 16

Ranges of estimated time frames to reach the next level of performance for 18 human-related performance capabilities



SOURCE: McKinsey Global Institute analysis

Natural language capabilities are critical for automation across many activities

Natural language understanding is of critical importance for a wide range of applications in the workplace. Despite some technical advances in this capability, including the accuracy of machine translation, machines still have a long way to go to achieve median human performance. The speed of technological advances in natural language capabilities in the future will substantially affect the timelines for automation overall.

The development of higher levels of natural language understanding is the single most important factor constraining the technical automation potential of activities for which the current performance level of technologies is insufficient. In the earliest scenario for automation, the current level of performance in natural language constrains the proportion of all activities that can be automated by 18 percent. In the latest scenario, the current level of natural language understanding would hinder automation of 40 percent of activities, since other capabilities will have reached their required performance levels by then.

Natural language processing capabilities have advanced in recent years and will likely continue to develop and improve, led by their use in auto (in-vehicle speech recognition), health care (clinical documentation improvements), and general personal use (virtual assistants in both mobile and fixed devices). Technology companies and venture capitalists continue to invest heavily in technologies related to natural language processing. Algorithms can write passages and new articles that are largely indistinguishable from those written by humans, and many experts expect continued rapid technical advances; by 2018, according to one prediction, machines could write as much as 20 percent of all business content.[72]

HISTORICAL TIME FRAMES FOR DEVELOPING SOLUTIONS THAT INTEGRATE MULTIPLE CAPABILITIES

Many of the 18 performance capabilities in our framework operate together. To arrange tables or dining areas as well as a human waiter, for example, machines will need some capacity for natural language understanding and generation, an ability to recognize known patterns, retrieve information, coordinate with multiple agents, and navigate. Furthermore, machines will need optimization and planning capabilities, fine motor skills, gross motor skills, and mobility. Developing solutions for this type of multi-capability activity requires time and technology.

To develop scenarios for the times required for solution development, we looked at historical precedents, examining almost 100 existing automation solutions that use hardware or software or both. We collected details of the development time and the technical capabilities that were integrated, recording the number of years from the initial research to the product launch, and identifying as many as three of the most relevant capabilities out of our 18 that were used. For example, Viv, an artificial intelligence technology that aspires to be the "intelligent interface for everything," combines logical problem solving with natural language understanding and generation, and took four years to integrate.[73] PillPick, a pharmacy automation system that helps hospitals eliminate the risk for medication errors during packaging and dispensing, combines fine motor skills with sensory perception, and took two years to develop.[74] For each activity for which a solution needs to be developed, we used the 25th and 75th percentile time frames for the capabilities whose historical development times at those points were longest. For more details of our methodology, see the technical appendix.

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[72] Bernard Marr, "Why management dashboards and analytics will never be the same again," *Forbes*, January 21, 2016; *Gartner predicts our digital future*, Gartner, October 6, 2015.

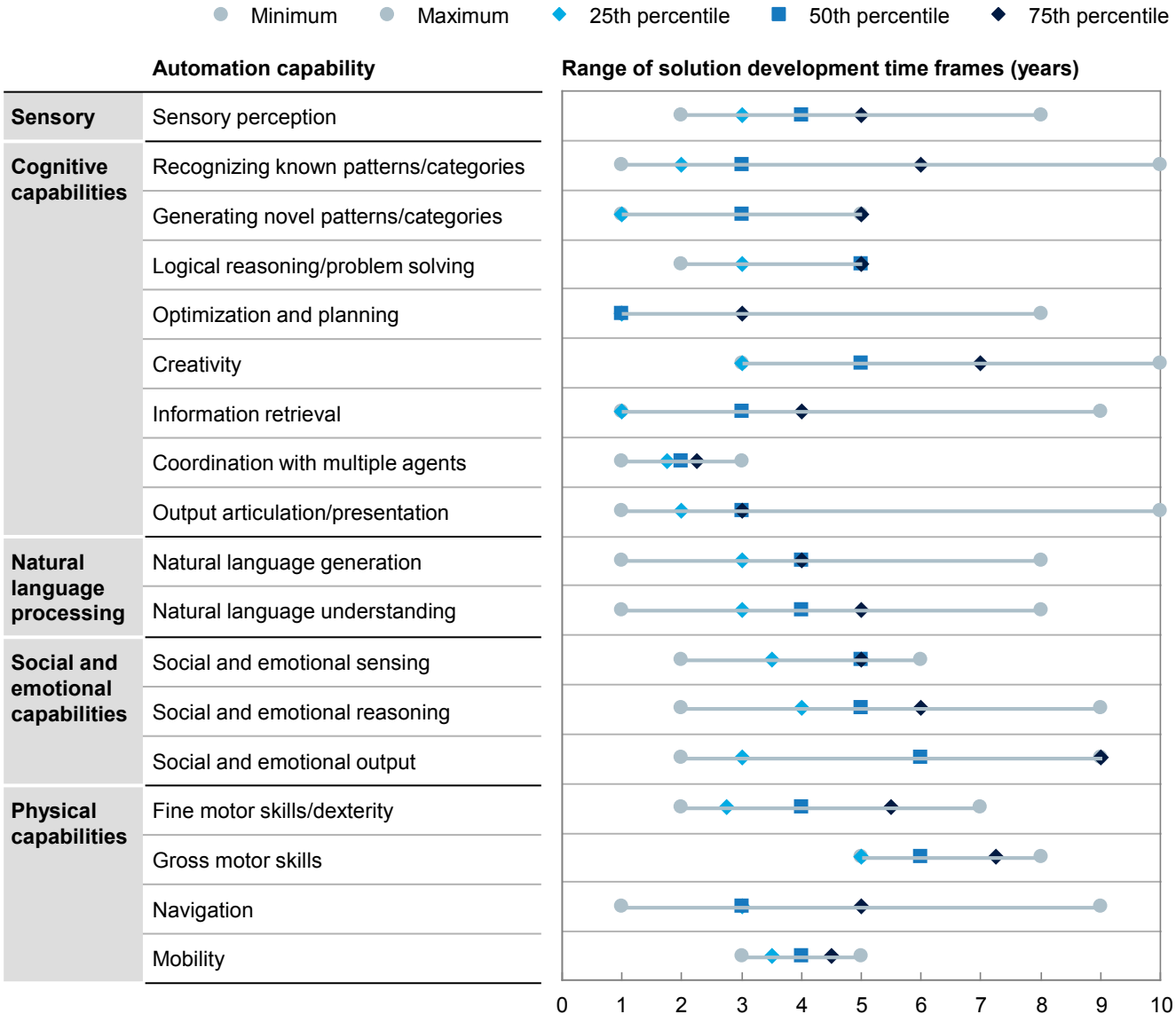
[73] Lucas Matney, "Siri-creator shows off first public demo of Viv, 'the intelligent interface for everything,'" *TechCrunch*, May 9, 2016.

[74] Anthony Vecchione, "New automated packaging system ensures patient safety," *Drug Topics*, November 22, 2004.

On average, we found that solution development takes one year for our earliest scenario and nine years for the latest. Some of the longest time frames were for social and emotional capabilities, whereas a number of the cognitive capabilities can be integrated much more rapidly (Exhibit 17).

Exhibit 17

Development timelines for solutions associated with each capability



SOURCE: McKinsey Global Institute analysis

MODELING THE ECONOMIC FEASIBILITY OF AUTOMATION

Our model assumes that the adoption of automation will begin after it becomes economically feasible—that is, when the economic benefits exceed the costs. These benefits include not only labor cost reductions, but also other performance improvements such as higher throughput or improved quality, as discussed earlier in this chapter. However, particularly early in the adoption cycle, the certainty that these benefits can be captured will be lower until they are demonstrated at scale. Thus, for the purposes of modeling, we assume that adoption begins when the cost of automating a particular activity (for a specific occupation in a country) is at parity for the cost of human labor for the same activity. To be fair, the certainty that labor cost savings can be completely captured will also be somewhat lower early in the adoption cycle. On a net basis, our model assumes that decision-

makers discount the benefits of initial labor cost savings by roughly the same amount as they believe the also uncertain non-labor cost-related benefits will be captured. In our experience, business leaders tend to view labor cost savings as being more predictable than other benefits.

Moreover, as we will discuss in the section on the international impact of automation, the overall lower level of wages in some emerging economies could mean that automation proceeds more slowly there than in advanced economies, where wages are higher than the global average. The cost of labor is not necessarily fixed, however. The related labor supply and demand dynamics are also a factor in the timeline for automation, as discussed above, but we do not model these dynamics.

ADOPTION OF AUTOMATION TECHNOLOGIES AFTER COMMERCIAL AVAILABILITY CAN TAKE YEARS

Even when a solution to automate an activity is commercially available, and implementing the solution makes rational economic sense, adoption still takes time—and can be very costly. Full adoption across an entire sector of any technology, particularly those that are integrated into the workplace, takes years. Individual decision makers must become aware of the potential, and there is always a spectrum of willingness to adopt, a phenomenon well documented in the research studying the diffusion of innovations.[75] Capital has to be deployed, technology acquired and installed, and processes transformed, within or across enterprises. Often, regulations need to change, and individual workers and employees have to become accustomed to the new technologies and processes.

From a review of the historical rate of adoption of previous technologies, the time from commercial availability to 90 percent adoption ranges from approximately eight to 28 years (for 50 percent adoption, the range is between about five and 16 years). This lag applies not only to hardware-based technologies that are capital-intensive and require physical installation; even technologies that are made available purely online take years to be adopted. A fast-growing consumer service such as Facebook began in 2004, and as of this writing, has not yet reached full adoption, even of non-China internet users (see Box 4, "Adoption of hardware vs. software/cloud-based technologies"). Furthermore, that decade of adoption does not even take into account previous instances of social networking services. Automation technologies that would be incorporated into the workplace require even more user and process changes than a consumer service that individuals can adopt independently.

To create scenarios for the rate of automation adoption, we analyzed adoption rates of 25 previous technologies to establish a range of timelines. We incorporated these historical examples into classic S-shaped adoption curves. (Exhibit 18).[76] We analyzed both hardware and software/online technologies, and we divided them into groups representing technologies with the fastest and the slowest adoption. Technologies with the fastest adoption rates include stents, airbags, MRIs, TVs, and online air booking. The slower adoption category include cellphones, personal computers, dishwashers, and pacemakers.

[75] Everett M. Rogers, *Diffusion of innovations*, The Free Press, 1962.

[76] S-shaped adoption curves were studied for consumer technologies by Frank Bass, "Comments on 'A new product growth model for consumer durables,'" *Management Science*, volume 50, number 12, December 2004.

Box 4. Adoption of hardware vs. software/cloud-based technologies

Hardware-based automation technologies, such as robots and self-driving vehicles, have requirements that can lengthen the time of adoption, that is, substantial capital requirements and the need to physically produce and deploy these technologies.

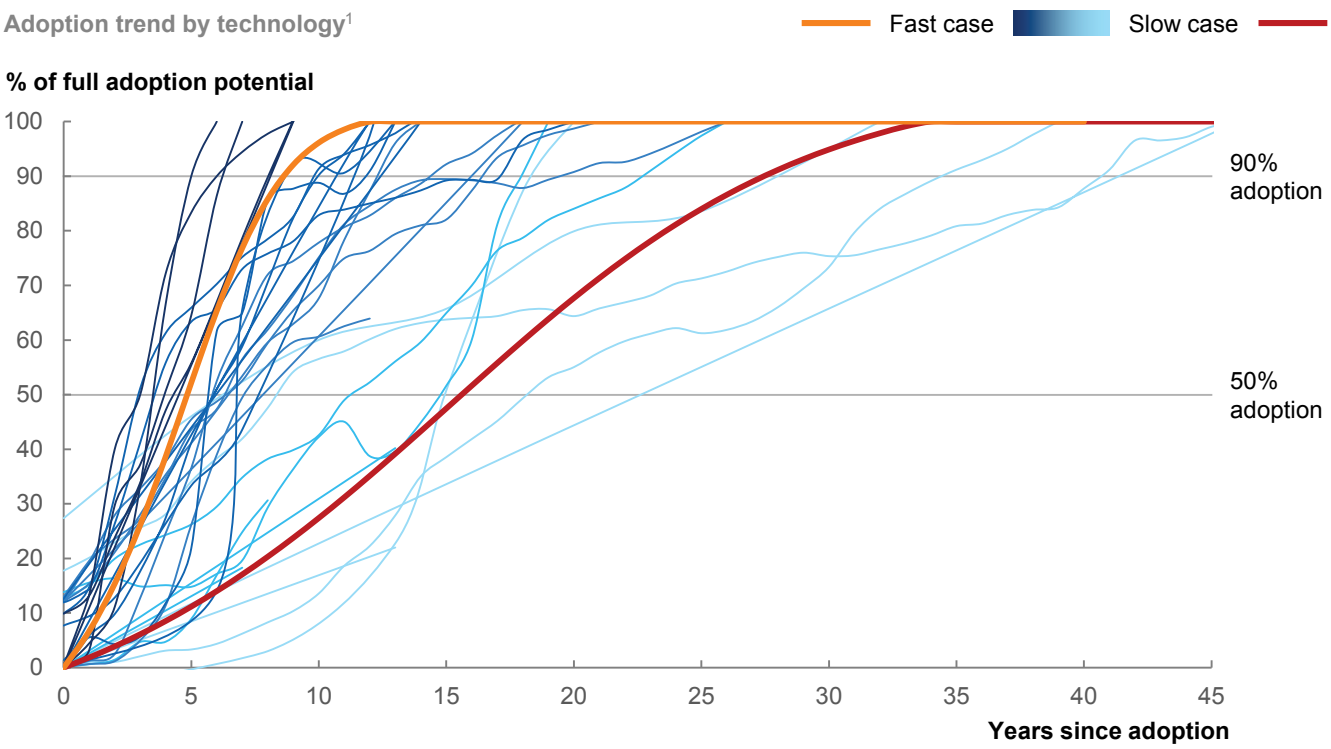
These requirements are much lower for software-based technologies, particularly those that are deployed through cloud technologies, that is, where the bulk of the computing occurs at centralized data centers that are accessed through networks. For these technologies, customers often pay for these services on an on-demand basis, reducing the need for the customer to deploy capital expenditure or manage for peaks in capacity (the cloud provider takes on these tasks). In general, the marginal cost of producing one more instance of a piece of software tends toward zero. And there are several cases of specific pieces of consumer applications, particularly those that have "gone viral," whose adoption seems to have been extraordinarily fast, such as Pokemon Go.

Does this mean that we should expect the adoption of software/cloud-based automation technologies to be much faster than for other technologies? In examining the historical record, we find that the adoption of software-based technologies falls within the envelope of the adoption rates of other technologies, that is, ranging from eight to 28 years to reach close to full adoption. In particular, for technologies that will be implemented in the workplace, the technical deployment of the technology represents only a fraction of the time and cost necessary to embed the technology into the processes and practices of an enterprise. We examined the adoption of cloud-based versions of enterprise resource planning (ERP), supply chain management (SCM), and customer relationship management (CRM). While these technologies have not yet reached a plateau in adoption, their adoption curves all fall within the range of adoption of other technologies. For instance, cloud CRM was first offered by Salesforce in 1999, and adoption of that technology still continues to grow.

Even for consumer online technologies, for which the bureaucracy of an enterprise is not a barrier to adoption, the behavior changes necessary for adoption take time to proliferate, particularly when these technologies are appropriately viewed by category, rather than a specific service (for example, Pokemon Go was not the first mobile game, and has not yet come close to full adoption). Take consumer social networking as another example. Facebook, only one example of a social networking platform, and not the first, was launched in 2004, and over a decade later, adoption continues to grow, both of that platform and other social networking platforms. Peer-to-peer (P2P) mobile payments is another consumer technology whose adoption rate falls within the envelope of other technologies.

Exhibit 18

Historic adoption curves for technological innovations



1 Technologies considered include airbags, antilock braking systems, cellphones, cloud CRM, cloud ERP, cloud SCM, color TVs, copper production through leaching, dishwashers, electronic stability control, embolic coils, Facebook, instrument landing systems, laparoscopic surgery, Lithium-ion cell batteries, microwaves, MRI, online air booking, P2P remote mobile payment, pacemakers, PCs, smartphones, stents, TVs, and VCRs.

SOURCE: McKinsey Global Institute analysis

The adoption of technologies within enterprises include factors beyond those that underpin consumer adoption. For example, the technology adoption literature discusses rank effects (that is, how the different individual characteristics of firms, such as their size, can affect the rate and extent to which they adopt new technologies) and the effects of competitive dynamics (that is, how the adoption of new technology by one company in an industry could influence the adoption of technology by other companies in that industry).[77] We do not model firm-level adoption dynamics; our model takes advantage of the fact that at a high level for economies and industries, the net result of the enterprise adoption factors are S-shaped curves that resemble those for consumer adoption.

This combination of technical feasibility, solution development, economic feasibility, and adoption enables us to model a set of scenarios that encompass various time frames for the pace of automation. To illustrate, we detail a specific example, driving heavy trucks (see Box 5, "Driving heavy trucks: Modeling scenarios for adoption of automation").

Adoption will ultimately depend on several factors include overcoming possible policy barriers and resistance to automation, which are meant to be captured in scenarios in the adoption stage of the model. For instance, given the importance of technological advances, intellectual property or regulatory issues could delay certain companies from being able to deploy specific technologies.

[77] See Massoud Karshenas and Paul Stoneman, "Rank, stock, order, and epidemic effects in the diffusion of new process technologies: An empirical model," *RAND Journal of Economics*, volume 24, issue 4, 1993, and Marc Anthony Fusaro, "The rank, stock, order and epidemic effects of technology adoption: An empirical study of bounce protection programs," *The Journal of Technology Transfer*, volume 34, issue 1, February 2009.

Box 5. Driving heavy trucks: Modeling scenarios for adoption of automation

To illustrate how we model scenarios for the pace and extent of automation, let us consider the single but widely performed work activity of driving, for one common occupation: heavy and tractor-trailer truck drivers.[1] This occupation is a significant source of employment, with more than 20 million workers worldwide, of whom 3.2 million are in India, 2.9 million are in China, 1.6 million are in the United States, and one million are in Japan.[2]

From a purely technical standpoint, the technologies to automate the required capabilities for this activity already exist. Some of the 18 individual performance capabilities we use in our framework are not required for this activity, including the three social and emotional capabilities, but for other capabilities, existing technology has demonstrated the necessary constituent performance levels to potentially enable driving. However, in order to automate the activity of driving ("Level 4" autonomy as classified by the Society of Automotive Engineers), these individual capabilities must be integrated into a solution, in other words the hardware and software that would constitute an autonomous driving truck must still be engineered.[3] Based on the historical time frames required to create solutions that involve the capabilities necessary to automate this activity, we estimate the time required to engineer such a solution could take more than seven years, which we use as basis for our latest adoption scenario. Conversely, because existing automation technology has met the levels of performance required across all of the necessary capabilities, and we do not know how far along pre-existing engineering efforts might be, our model also accepts the possibility that an organization could announce a Level 4 autonomous truck immediately, which we use as the basis for our earliest adoption scenario.

Then comes the question of economic feasibility. In our model, adoption begins when the cost of automation reaches parity with the cost of human labor, for an individual occupation within a specific market (which we model at the level of countries). Of course, there are other economic benefits which could contribute to the business case for automation. In the case of driving heavy trucks, for example, these could include higher fuel efficiency, improved safety, increased asset utilization, and so on. However, particularly early in the adoption cycle, the certainty that these benefits can be captured will be lower until they are demonstrated at scale. To be fair, the certainty that labor cost savings can be completely captured will also be somewhat lower early in the adoption cycle. On a net basis, our model essentially assumes that decision-makers discount the benefits of initial labor cost savings, because of initial uncertainty, by roughly the same amount as they believe the also uncertain non-labor cost-related benefits will be captured.

1 The detailed work activity title is "operating vehicles or material-moving equipment" in the US Bureau of Labor Statistics taxonomy.

2 US Bureau of Labor Statistics; Oxford Economic Forecasts.

3 *Taxonomy and definitions for terms related to driving automation systems for on-road motor vehicles*, Society of Automotive Engineers, September 30, 2016.

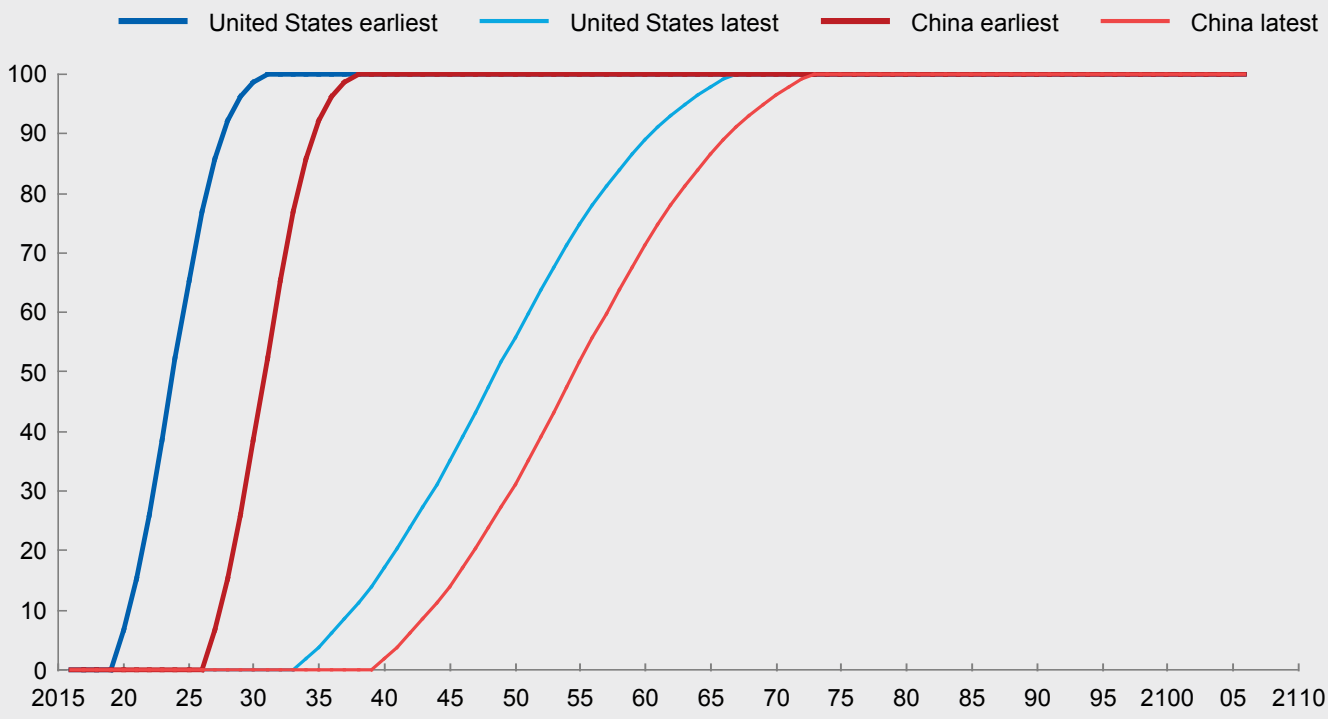
Box 5. Driving heavy trucks: Modeling scenarios for adoption of automation (continued)

Using these assumptions, the time at which we model adoption beginning is sensitive to the cost of labor in different markets. For our example, we compare the United States with China (Exhibit 19). Total wages paid to heavy and tractor-trailer truck drivers exceed $328 billion worldwide, of which almost $60 billion is paid in the United States, and more than $33 billion is paid in China. Because of the significantly higher level of wages in the United States, automation is modeled to become economically feasible faster there. Under our scenarios, the cost of the automation could be below US wage levels within three to ten years after Level 4 autonomy is available, whereas in China it could take 10 to 16 years.

Finally, once automation becomes economically feasible, adoption can still be a long process, even when the business case is compelling. In this case, there are approximately two million tractor-trailers in the United States, each of which is typically on the road for about 20 years, and cost about $160,000 apiece. Replacing the current fleet would cost $320 billion, not including the additional technology for autonomous driving (whose cost we do model as declining over time), and would be certain to take many years.

Exhibit 19

Modeled adoption of operating vehicles or material-moving equipment, United States and China[1]



1 The detailed work activity (DWA) is 4.A.3.a.4.I01.D06. Occupations using this activity include: Heavy and Tractor-Trailer Truck Drivers, Industrial Truck and Tractor Operators, etc.

SOURCE: US Bureau of Labor Statistics; McKinsey Global Institute analysis

[4] There could be a potential retrofit opportunity for more recent vehicles with electronic control systems, and perhaps the number of autonomous trucks necessary to meet current demands could be lower than the current number of trucks because of higher utilization. However, the basic point remains, that adoption will take years and large amounts of capital to reach its maximum level.

MODELING THE PACE AND EXTENT OF AUTOMATION ACROSS ACTIVITIES AND SECTORS

Each of the four stages affects the overall pace of automation reflected in the model. Technical feasibility accounts for much of the variance in our modeled scenarios, but economic feasibility is also a significant factor, especially in the earliest scenario, where our modeling suggests it could hold up adoption and deployment for eight to nine years for some activities (Exhibit 20).

Several of the 18 performance capabilities are potential bottlenecks in the model. The types of activities that today have among the lowest potential for automation, such as managing and developing people, applying expertise and experience, and interfacing with stakeholders, will all require substantial further advances in social and emotional capabilities, as well as in natural language understanding and creativity. These activities typically require at least a median-level human performance in social and emotional capabilities, for example. As we have seen, these capabilities are particularly difficult to develop, and most related technologies are in nascent stages and may take several decades to mature. This potentially could delay the development, integration, and deployment of automation as a whole.

Along with timelines for capability development, whether hardware or just software is required is also a key determinant of scenarios in the model, because this will affect the economic viability of automation. Hardware requires significant capital spending, and thus we model with relatively higher initial costs. For example, sensory perception capabilities need cameras and sensors. Mobility requires wheels or other hardware that enable machines to move. Software solutions, by comparison, are relatively less expensive to deploy and thus we model with relatively lower costs compared to hardware solutions. Some 98 percent of the solutions for predictable physical activities are hardware ones, whereas hardware represents only about 30 percent of processing data solutions.

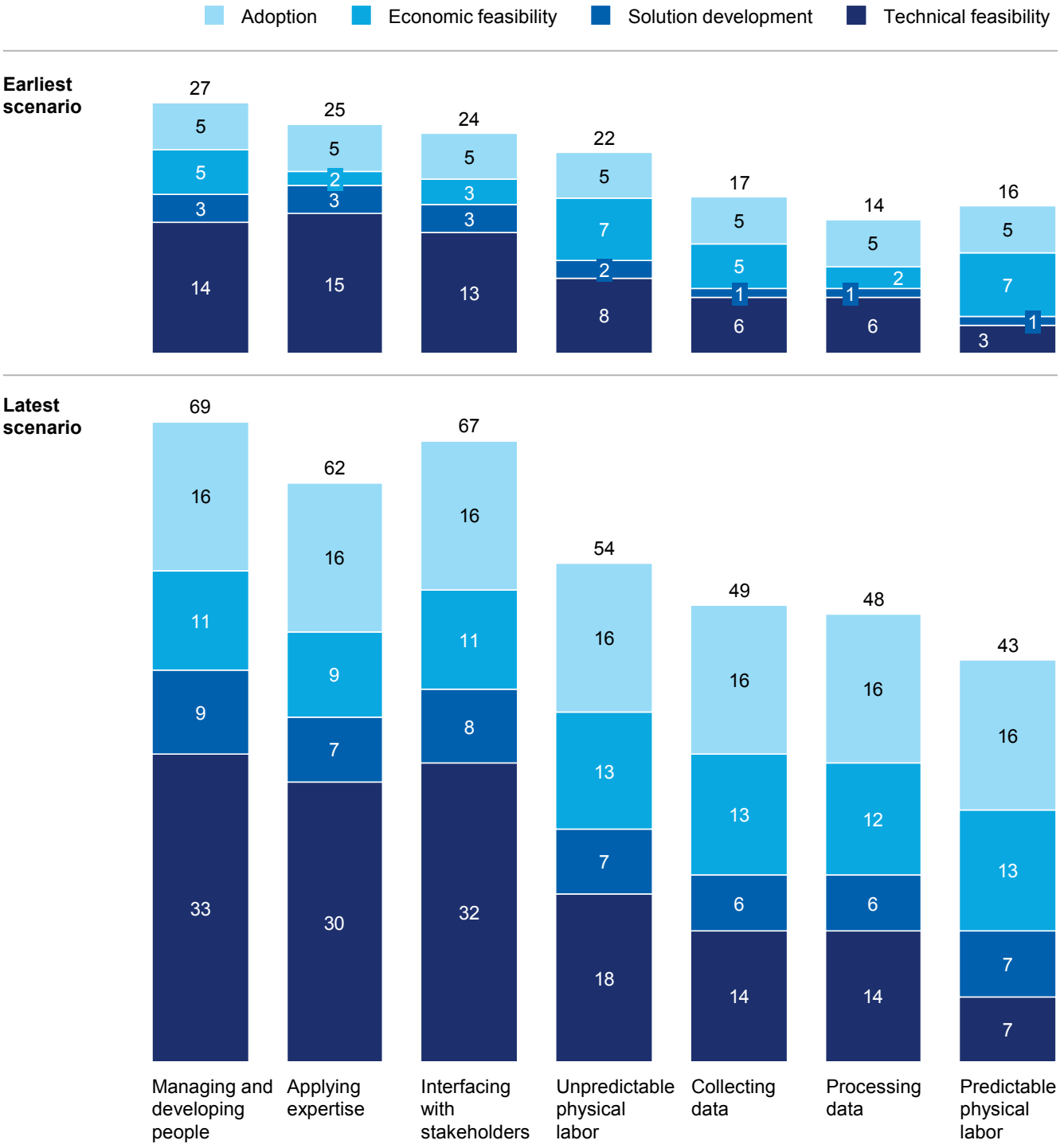
This hardware-software distinction helps explain differences in the pace of automation adoption across different types of activities. For example, under our earliest scenario, the model suggests that unpredictable physical labor activities—which require substantial hardware for successful automation—will have much slower adoption rates than for activities that consist of processing data, which primarily require software solutions.

As we will detail in our discussion of country differences below, the modeled time frame for physical activities is longer in emerging economies largely because of lower wages compared to the cost of hardware-based automation solutions.

Exhibit 20

Differences in the adoption timing are primarily driven by technical feasibility, and in the earliest scenario, also by economic feasibility

Decomposition of average time to 50% adoption into stages by types of activities, global
Years



Share of time automatable[1] %	14	23	24	38	72	73	74

1 Percentage of time automatable by adapting currently demonstrated technology.
NOTE: Numbers may not sum due to rounding.

SOURCE: US Bureau of Labor Statistics; McKinsey Global Institute analysis

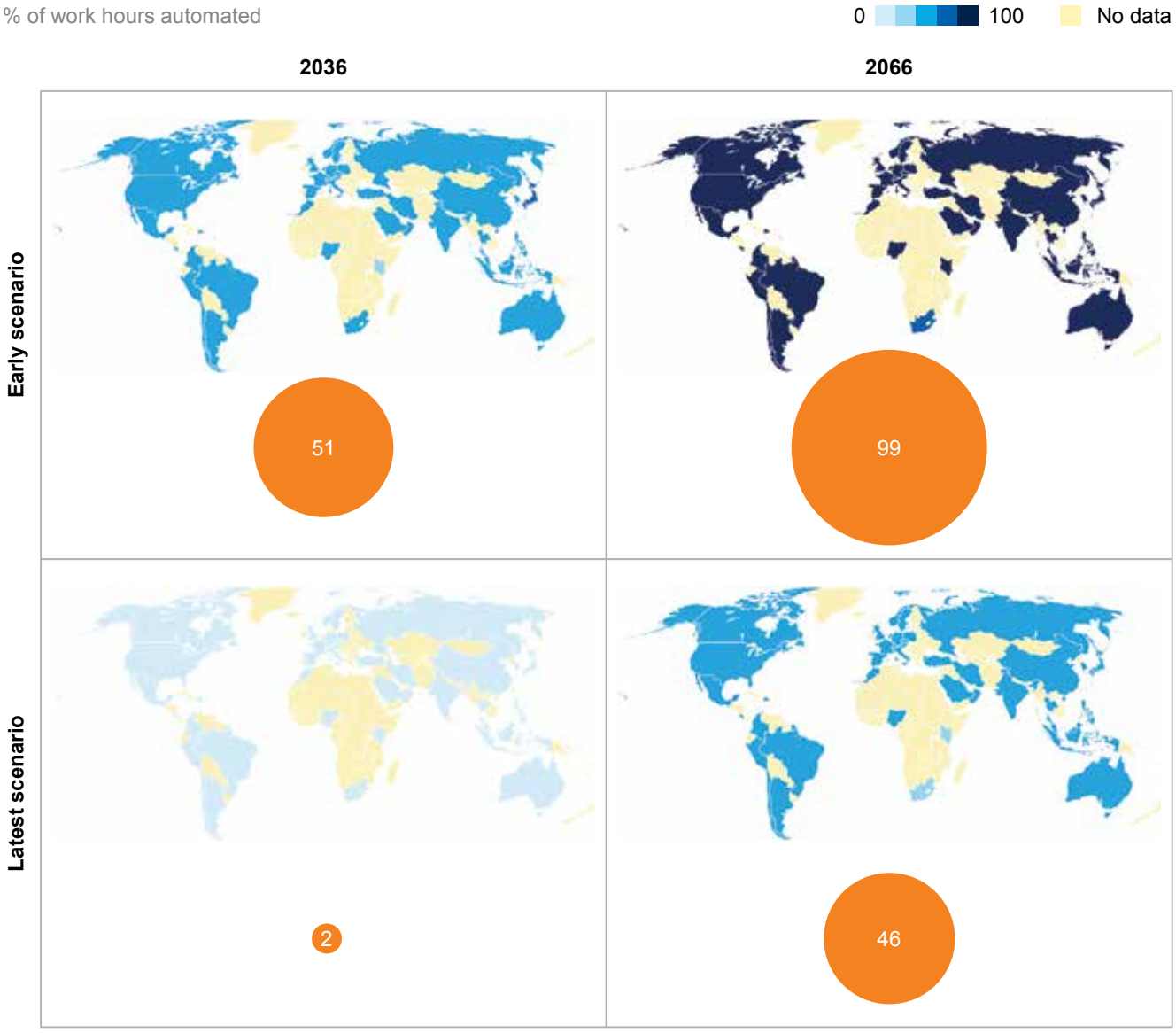
GLOBAL TIMELINES: MODELING ADOPTION OF AUTOMATION BY COUNTRY

Automation will be a global force that affects all countries, whether they are emerging economies or advanced ones. In the earliest scenario we modeled, automation could account for more than 50 percent of working hours in two-thirds of countries within just 20 years, by 2036. In the latest scenario we modeled, more than half of all countries will have 50 percent automation or more within 50 years, by 2066 (Exhibit 21).

In the early years of automation adoption, our model shows the impact being felt most strongly in a few advanced economies, especially Germany, Japan, and the United States. These countries have both high wages and major industries that already have a high potential for automation based on existing technologies. As automation is adopted in more countries around the world, the impact will become especially pronounced in China and India, because of their large workforce. Initially, our model shows automation affecting workers there in manufacturing and retailing because of their high automation potential, but in the longer term its largest impact will be in agriculture, which is where hundreds of millions of Chinese and Indians earn their livelihood.

Exhibit 21

Automation impact will be global under multiple modeled scenarios



SOURCE: US Bureau of Labor Statistics, 2014 O*Net database; McKinsey Global Institute analysis

Adoption of automation could be faster initially in advanced economies than emerging ones because of wage levels and integration solution costs. Higher wages in advanced economies and hardware costs will likely make automation economically viable faster there than in emerging economies. In Japan, the United States, and Europe's five largest economies—France, Germany, Italy, Spain, and the United Kingdom—this is likely to mean earlier adoption in a range of sectors, especially manufacturing and services. In the United States, for example, our model shows manufacturing, retail, health care, transportation, accommodation and food services, and administrative services to be among the first sectors affected. In terms of the impact on workers, sectors that are large employers, such as health care, will be affected even though their expected automation adoption rate (48 percent) is lower than some other high-adoption sectors such as accommodation and food services (83 percent) in 2036 under earliest scenario.

Initially, technologies with physical capabilities are the most likely to become available, and will be increasingly adopted in sectors such as manufacturing and retail. As adoption in these sectors approaches 100 percent, their contribution to overall adoption rates will hit a plateau. Once the technology to replicate cognitive and natural language understanding capabilities has been mastered, services sectors globally will be affected, and the pace and extent of overall automation will pick up, especially in advanced economies with large service sectors.

For all advanced economies, the business case for automating will become stronger as solutions for technology integration in the workplace become cheaper. Exhibit 22 shows the estimated wages corresponding to automation adoption by country.

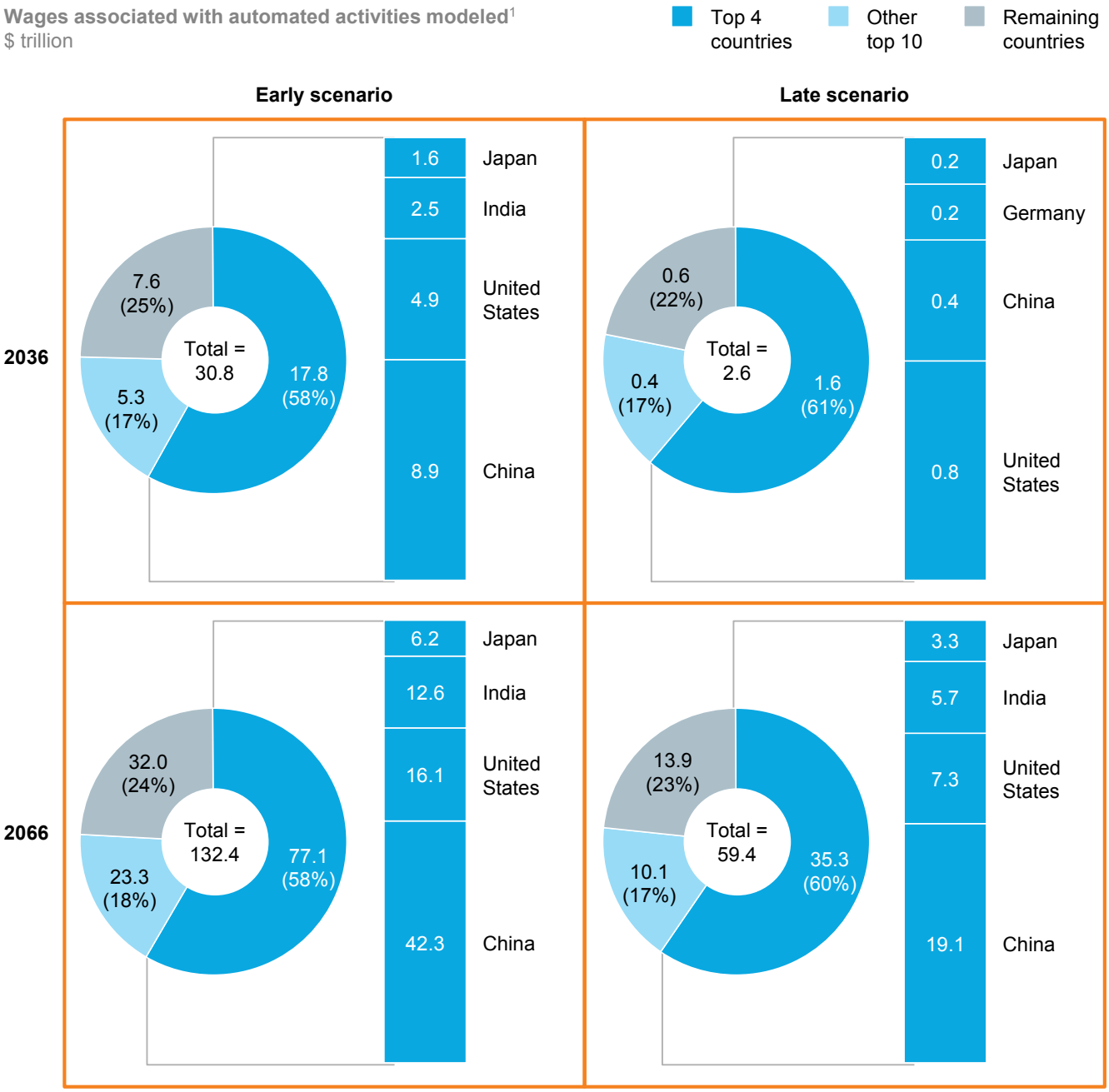
In China, India, and other emerging economies, cost and relative lower wage levels will likely delay adoption. Manufacturing relies heavily on predictable physical activities, and automating them will require hardware solutions that require considerable up-front capital investment. This may not be economical in emerging economies, given the lower cost of labor there, until the cost of the solutions drops sharply.

Emerging economies could achieve a pace of automation similar to that of advanced economies if solutions become cheaper, possibly through localized innovation. Adoption could also be accelerated as a result of policy measures, increased competition, a lack of legacy systems that could be a brake on automation implementation, and a high degree of technological literacy.

In sectors where software solutions to integrate automation technologies will be required, the pace of automation across emerging and advanced economies could be similar. For example, we model similar rates of automation adoption in the finance and insurance sectors—which are characterized by a high proportion of data processing and collection—in both the United States and China. Software, which has a relatively minimal marginal cost, accounts for just over half the technology integration solutions needed in this sector, and the global disparity in wages is not as pronounced in some areas. For example, architects or investment bankers in emerging economies are relatively well paid. Moreover, wage distribution globally is fairly similar for real estate, rental and leasing activities, health care, and social assistance.

Exhibit 22

Wages associated with automated activities are modeled to be highly concentrated in countries with higher wages and populations



1 Forty-six countries used in this calculation, representing 78% of global labor force; calculations based on current FTEs in each sector, not considering FTE growth and sector migration.
NOTE: Not to scale. Numbers may not sum due to rounding.

SOURCE: US Bureau of Labor Statistics; McKinsey Global Institute analysis

The largest impact on workers could be felt in labor-intensive sectors in China and India, whereas in other countries it will be felt across multiple sectors

In analyzing the potential impact of automation on workers, we make a number of assumptions. We calculate the impact based on the current number of full-time equivalents in each sector and do not take into account any possible growth in their numbers per sector or the movement of labor from one sector to another. We also assume that the technologies we identify will emerge throughout the world and that they will be adopted only when they become economically feasible.

China and India both have very large farming sectors, with about 230 million people out of a working population of 450 million in India alone working in agriculture. In China, more than 200 million work on the land out of a total workforce exceeding 770 million. Given the employment size of this sector, even a relatively low rate of automation adoption of about 10 percent could have significant employment consequences in both countries.

In both China and India, the impact of automation on employment could also be felt in the retail and manufacturing sectors, as both have a relatively high potential for automation and a sizable labor force. In the five major European countries, Japan, and the United States, the employment impact will likely be spread across multiple sectors, especially in the event that large-scale automation begins relatively soon. A detailed view of our model of automation impact on individual countries is available via an interactive graphic online.[78]

•••

Automation technologies will be increasingly adopted in every industry, every sector, and every country in the world, but there is considerable uncertainty about the speed and intensity with which they will arrive. These will depend on several key variables, both technical and economic. Machines will need to be able to simulate the full range of human performance capabilities, and solutions to integrate the technology into the workplace will need to be adopted. Only when costs have fallen below wage levels will automation become economically viable, and ultimately adopted. All of this could happen within two decades for a wide range of activities and sectors, but it could also take much longer. Whatever the time frame, the consequences will be significant not just for individual workers and sectors but also for the global economy as a whole. In the next chapter we look at how automation could upend some cherished notions about productivity, growth, and development.

[78] The data visualization can be viewed online at **http://public.tableau.com/profile/mckinsey.analytics#!/**

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5. AN ENGINE OF PRODUCTIVITY

The world is in need of a new engine of GDP growth. Shifting demographics in many countries brought on by aging populations and declining birthrates are reducing the share of working-age populations and creating an economic growth gap: in the not-so-distant future, without an acceleration in productivity growth, there will not be enough workers for countries to meet their aspirations for growth in GDP per capita.

In this context, automation could be a significant opportunity. Our estimates suggest it could help serve as a new productivity engine for the global economy, bridging that economic growth gap. Automation could raise global productivity by as much as 0.8 to 1.4 percent annually. While that will not be enough to ensure all countries meet their per capita GDP growth aspirations, it will make a major contribution toward that goal.

In order for this growth to take place, people will need to keep working—alongside the robots that will help provide the productivity boost. Even with automation, a deficit of labor is more likely than a surplus. Yet the adoption of automation will change the nature of work, and the public debate about it often focuses on the prospect that it could lead to very large-scale unemployment. Such fears are not new: already back in 1966, a US government commission noted concerns that technological change "would in the future not only cause increasing unemployment, but that eventually it would eliminate all but a few jobs, with the major portion of what we now call work being performed automatically by machine."[79]

In fact, the large-scale shifts in employment that automation will enable are of a similar order of magnitude to the long-term technology-enabled shift in the developed countries' workforces away from agriculture in the 20th century. That movement did not result in long-term mass unemployment because it was accompanied by the creation of new types of work not foreseen at the time. We cannot definitively say whether things will be different this time. But our analysis does show that automation will fundamentally alter the workplace, requiring all workers to cohabit extensively with technology and reshaping the corporate landscape.

THE PRODUCTIVITY BOOST FROM AUTOMATION COULD BRIDGE A LOOMING ECONOMIC GROWTH GAP

GDP growth was exceptionally brisk over the past half century, driven by the twin engines of employment growth and rising productivity. However, declining birthrates and the trend toward aging in many advanced and some emerging economies mean that peak employment will occur in most countries within 50 years. The workforce in Japan is already shrinking in size, and the total number of workers in China will start to decline within a decade. This expected decline in the share of working-age population will place the onus for future economic growth far more heavily on productivity gains. Employment growth of 1.7 percent annually between 1964 and 2014 in the G19 countries and Nigeria is set to fall to just 0.3 percent per year.[80]

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[79] *Technology and the American economy, Report of the National Commission on Technology, Automation and Economic Progress*, US Department of Health, Education and Welfare, February 1966.

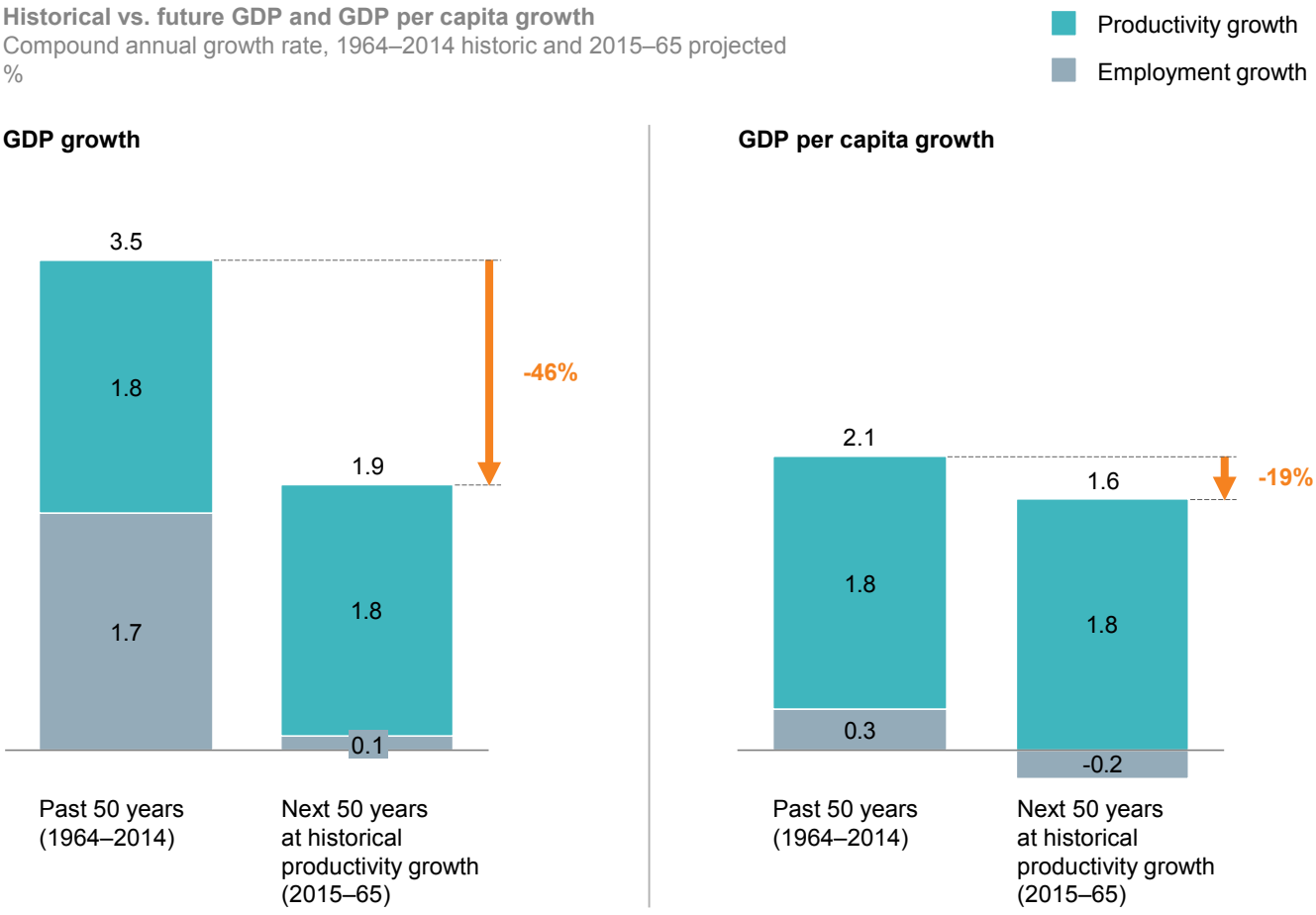
[80] The global productivity challenge created by waning employment growth is detailed in our report *Global growth: Can productivity save the day in an aging world?* McKinsey Global Institute, January 2015. The G19 countries are the G20 minus the European Union: Argentina, Australia, Brazil, Canada, China, France, Germany, India, Indonesia, Italy, Japan, Mexico, Russia, Saudi Arabia, South Africa, South Korea, Turkey, the United Kingdom, and the United States. Including Nigeria, these 20 countries generate more than 80 percent of global GDP.

Prior MGI research has shown that even if productivity growth maintains its 1.8 percent annual rate of the past half century, the rate of GDP growth will fall by as much as 40 percent over the next 50 years. On a per capita basis, the GDP growth decline is about 19 percent (Exhibit 23). In order to compensate for slower employment growth, productivity would need to grow at a rate of 3.3 percent annually, or 80 percent faster than it has grown over the past half century.[81]

Exhibit 23

Without an acceleration in productivity growth, demographic trends will cut GDP growth by nearly half, causing a decline in historic GDP per capita growth rate

Historical vs. future GDP and GDP per capita growth
Compound annual growth rate, 1964–2014 historic and 2015–65 projected
%



NOTE: Numbers may not sum due to rounding.

SOURCE: The Conference Board Total Economy database; United Nations Population Division; McKinsey Global Institute analysis

The size of the workforce over the next 50 years is too small to maintain current per capita GDP growth without accelerating productivity growth

An economic growth gap has opened up as a result of the shrinking workforce. The number of full-time equivalents needed just to maintain the current GDP per capita over the next 50 years is larger than the number of workers who will be available, given demographic trends in most countries. We estimate this gap in economic output as being about 130 million full-time equivalents (FTEs) for the G19 countries and Nigeria alone. (In other words, the economic output equivalent to an additional 130 million full-time workers would be needed to maintain current GDP per capita, assuming no productivity gains.) If countries are to achieve more ambitious longer-term growth in line in line with their development and

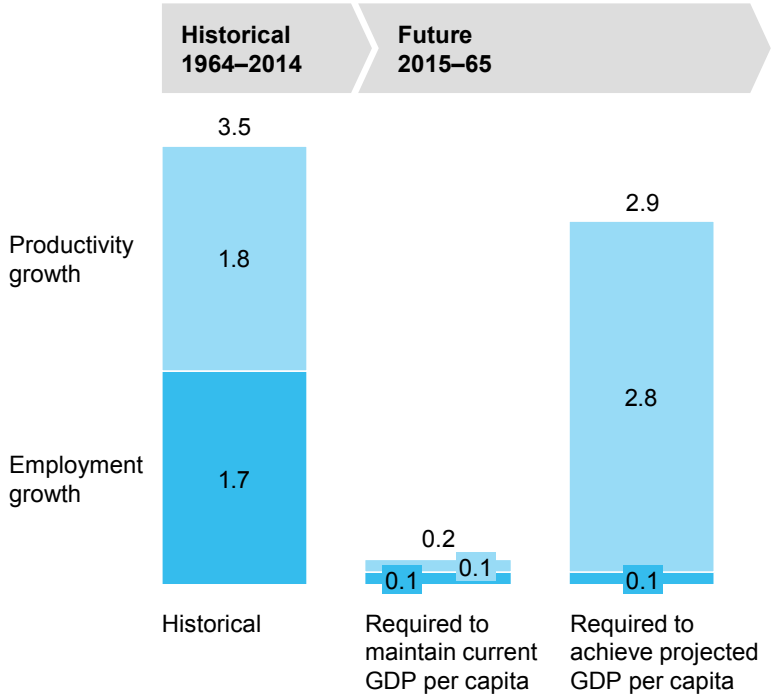
[81] *Global growth: Can productivity save the day in an aging world?* McKinsey Global Institute, January 2015. Our estimate of employment growth's contribution to GDP growth in this report differs slightly from this earlier research, as we have assumed productivity measured in each country, rather than a global average.

the aspirations of their citizens goals (that is, growth in GDP per capita), the gap would be considerably larger—the economic output of about 6.7 billion FTEs by 2065 (Exhibit 24).

Exhibit 24

Demographic trends are creating a pressing need for an acceleration in productivity growth

GDP growth for G19 and Nigeria
Compound annual growth rate
%



	Historical	Required to maintain current GDP per capita	Required to achieve projected GDP per capita
GDP per capita growth Compound annual growth rate %	2.1	0	2.5
Full-time equivalent gap[1] Billion		0.1	6.7

1 Additional full-time equivalents (FTEs) needed to achieve growth target.
NOTE: Numbers may not sum due to rounding.

SOURCE: The Conference Board Total Economy database; United Nations Population Division; McKinsey Global Institute analysis

For the purposes of our analysis, we based our country-level GDP projections on McKinsey's proprietary Global Growth Model. This model projects a global GDP growth rate of 2.9 percent, resulting in an annual productivity growth of 2.8 percent. For advanced economies overall, the projections in the McKinsey model result in a compound annual growth of GDP per capita to 2030 of 1.4 percent, and 3.4 percent for emerging economies.

For the G19 countries and Nigeria that we discuss in this report, the model projects GDP growth of 2.7 percent, resulting in GDP per capita growth of 2 percent to 2030.[82]

The growth gap between the projected growth and growth that must be provided by productivity increases is most pronounced in fast-growing countries such as China, India, Indonesia, and Nigeria, but it is also prevalent in Germany and Japan and other countries that are already experiencing a slowdown or decline in the working-age population. Furthermore, productivity growth has slowed in many countries.[83]

Exhibit 25 illustrates the need for continued productivity growth, even just to maintain GDP per capita (an admittedly unsatisfactory outcome) in both the medium term (by 2030) and in the long term (by 2065) for the 20 largest economies in the world. Without productivity growth, aging countries with older demographics simply would not have enough workers needed to maintain GDP per capita. Younger countries have more than enough workers to maintain GDP per capita.

Automation can help bridge the projected growth gap by compensating for the slowdown in workforce growth

Our analysis of the automation adoption scenarios suggests that automation could help bridge the projected growth gap caused by a deficit of full-time equivalents worldwide. Automation alone will not be sufficient to achieve long-term target growth across the world, given the decline in the working-age population and the need for high productivity to achieve that target. Especially in fast-growing countries, other measures to boost productivity will be needed. However, notably, the productivity gains from automation could suffice to at least maintain today's GDP per capita.

Our methodology takes into account only labor substitution gains. Other performance gains—in the form of improved quality, fewer breakdowns, greater safety, and so on—would come on top of this overall productivity boost. We also assume that human labor displaced by automation would rejoin the workforce and be as productive as it was in 2014, that is, new demand for labor will be created. In some ways, this is a conservative assumption, given that if automation produces productivity gains, we assume displaced labor reenters the workforce at a lower level of productivity than the level of labor productivity at the time the displacement occurs. Others could argue that the activities performed by workers who are displaced by automation could have lower levels of economic output than the activities that had been taken over by machines. In any case, it is vital that there be new demand for labor displaced by automation.

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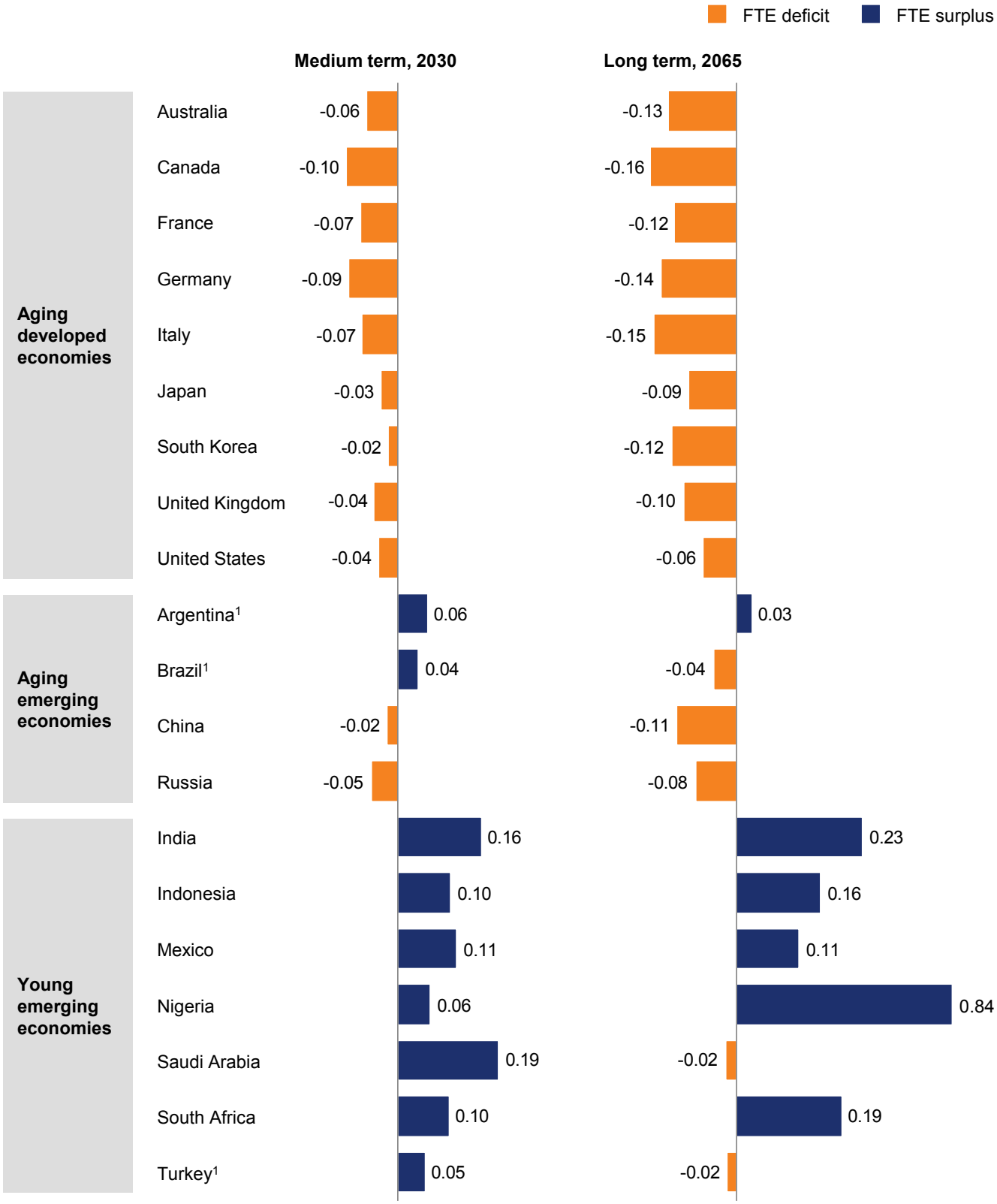
[82] McKinsey & Company's proprietary Global Growth Model provides complete time-series data for more than 150 concepts and 110 countries over 30 years. It incorporates more than a dozen major international databases from such institutions as the United Nations, the World Bank, the International Monetary Fund, and the Bank for International Settlements. The structure of the model emphasizes the drivers of economic growth, including demographic factors, education, energy supply, physical capital, and some determinants of total factor productivity. It captures the long-term effects of urbanization and industrialization, as well as the impact of sociopolitical institutions, especially on finance and governance. Because business-cycle fluctuations affect growth in the short term, the model also links trade and international capital flows, credit and asset markets, and the monetary relationships that determine inflation, interest rates, and exchange rates. See the technical appendix for more details. The growth model shows a compound annual growth rate for GDP and GDP per capita for 2015 to 2030 by country as follows: China 5.1 percent GDP, 4.9 percent GDP per capita; France 1.0 percent and 0.6 percent; Germany 1.3 percent and 1.6 percent; India 5.8 percent and 4.8 percent; Italy 0.5 percent for both GDP and GDP per capita; Japan 1.0 percent and 1.3 percent, United Kingdom 1.5 percent and 1.0 percent; United States 2.2 percent and 1.4 percent.

[83] *Global growth: Can productivity save the day in an aging world?* McKinsey Global Institute, January 2015.

Exhibit 25

Aging countries have the greatest need for productivity growth just to maintain GDP per capita

FTE gap between FTE projections and number of FTEs to maintain current GDP per capita, 2030 and 2065
Gap indexed as % of number of FTEs in 2014



1 Countries on borderline of demographic categorization between aging and growing populations (under 1 million FTE surplus/deficit in 2065) categorized according to demographic statistics and grouping of similar regional economies.

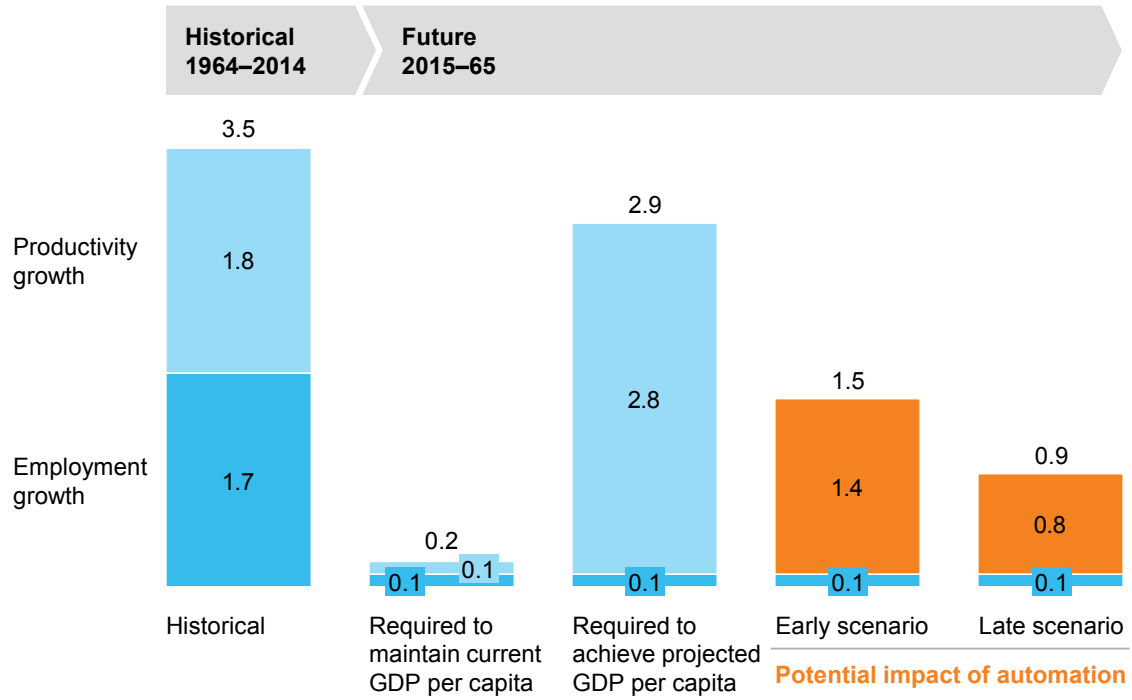
SOURCE: The Conference Board Total Economy database; International Labour Organisation; United Nations Population Division; Statista; McKinsey Global Institute analysis

Only considering the labor substitution effects on current work activities, and assuming that displaced labor reenters the workforce at 2014 levels of productivity, we estimate that, by 2065, the productivity enabled by automation could potentially increase economic growth by 0.8 percent to 1.4 percent annually, the equivalent of 1.1 billion to 2.3 billion FTEs. (Exhibit 26).

Exhibit 26

Globally, automation could become a significant economic growth engine as employment growth wanes

GDP growth for G19 and Nigeria
Compound annual growth rate
%



	Historical	Required to maintain current GDP per capita	Required to achieve projected GDP per capita	Potential impact of automation: Early scenario	Potential impact of automation: Late scenario
GDP per capita growth Compound annual growth rate %	2.1	0	2.5	0.5–1.1	
Full-time equivalent gap[1] Billion		0.1	6.7		

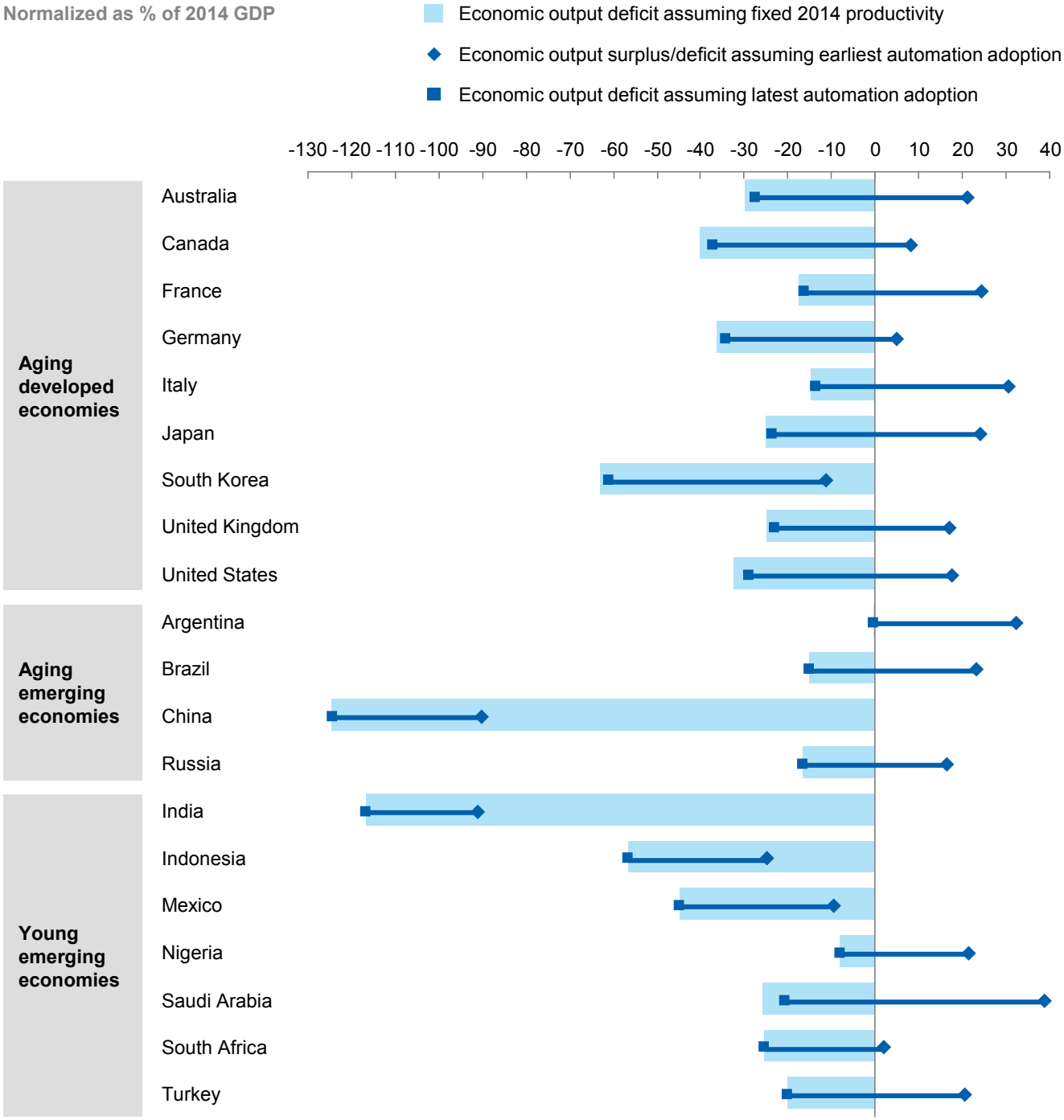
1 Additional full-time equivalents (FTEs) needed to achieve growth target.
NOTE: Numbers may not sum due to rounding.

SOURCE: The Conference Board Total Economy database; United Nations Population Division; McKinsey Global Institute analysis

Exhibit 27 shows what the effect of automation could be on the gap between growth targets and economic output by country for the G19 and Nigeria. We discuss individual countries and groupings of countries in more detail later in this chapter.

Exhibit 27

Modeled effects of automation on the gap between growth targets and economic output by 2030



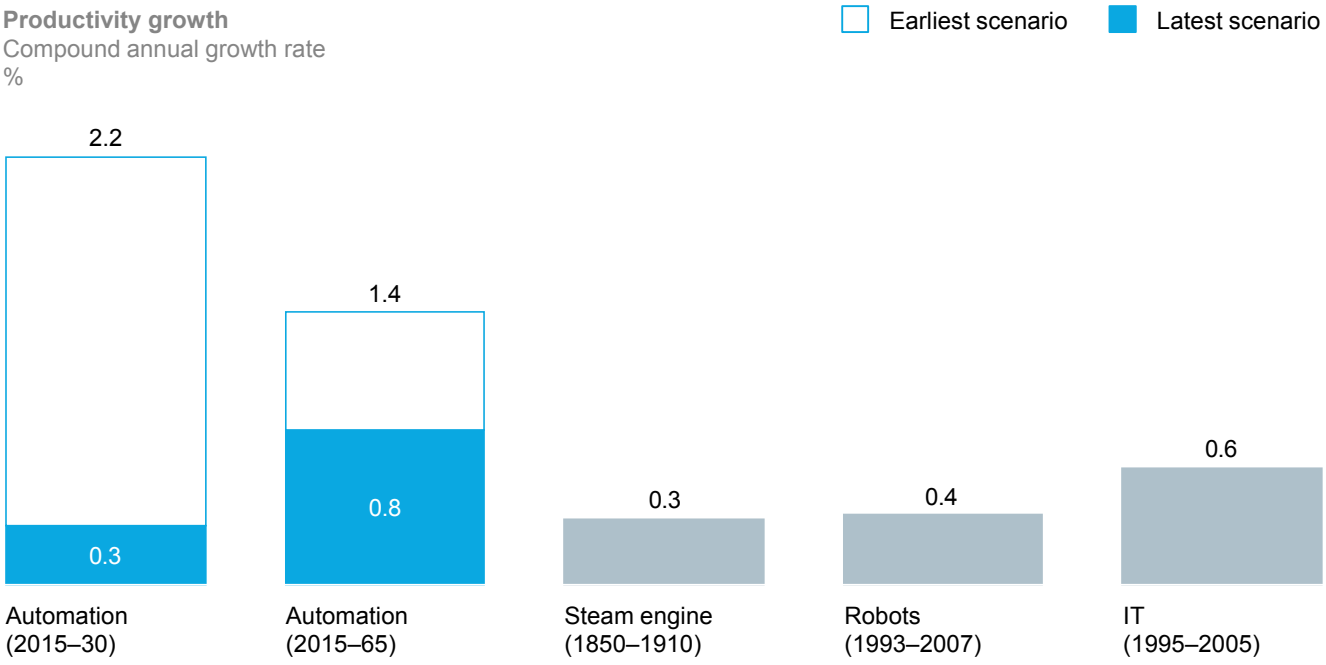
NOTE: Surplus/deficits calculated as gap to projected GDP in 2030 as a percentage of 2014 GDP by using population projections; base case (no automation) assumes 2014 productivity. Assumes no other productivity growth than that provided by automation.

SOURCE: The Conference Board Total Economy database; International Labour Organization; United Nations Population Division; McKinsey Global Institute analysis

While our estimates of the productivity boost from automation are substantial, they are of an order of magnitude comparable to major technologies that have been introduced in the past two centuries. For example, between 1850 and 1910, the steam engine has been estimated to have enabled productivity growth of 0.3 percent per annum. Analyses of the introduction of robots in manufacturing and IT estimate that they have accounted for annual productivity increases of 0.4 percent and 0.6 percent, respectively (Exhibit 28).[84] One difference is that automation of current work activities as we have analyzed it encompasses multiple technologies, not just one.

Exhibit 28

Automation of existing activities could increase productivity at magnitudes similar to other major technologies



NOTE: We include multiple technologies in our analysis of "automation," so these technologies are not entirely comparable, but meant to provide an order of magnitude comparison.

SOURCE: Nicholas Crafts, "Steam as a general purpose technology: A growth accounting perspective," *Economic Journal*, volume 114, issue 495, April 2004; Mary O'Mahony and Marcel P. Timmer, "Output, input, and productivity measures at the industry level: The EU KLEMS database," *Economic Journal*, volume 119, issue 538, June 2009; Georg Graetz and Guy Michaels, *Robots at work*, Centre for Economic Performance discussion paper 1335, March 2015; McKinsey Global Institute analysis

The productivity potential of automation is a multiplier of other productivity levers. Economies that have relatively low productivity can also accelerate productivity growth through other means, for example by adopting best practices from other countries with high productivity, in order to reap the full benefits of automation's potential and achieve a faster growth trajectory. Previous MGI research has estimated that about three-quarters of potential productivity improvements could come from the broader adoption of best practices and technologies, as companies catch up with sector leaders. The remaining one-quarter would come from technological, operational, and business innovations that go beyond best practices and push the frontier of the world's GDP potential. Business leaders and policy makers can encourage this acceleration of productivity by removing barriers to competition in service sectors, investing in physical and digital infrastructure, exploiting

[84] Nicholas Crafts, "Steam as a general purpose technology: A growth accounting perspective," *Economic Journal*, volume 114, issue 495, April 2004; Mary O'Mahony and Marcel P. Timmer, "Output, input, and productivity measures at the industry level: The EU KLEMS Database," *Economic Journal*, volume 119, issue 538, June 2009; George Graetz and Guy Michaels, *Robots at work*, Centre for Economic Performance discussion paper number 1335, March 2015.

data to identify transformational improvement opportunities, opening economies to cross-border flows, and crafting a regulatory environment that fosters increased productivity and innovation.[85]

THE IMPACT OF AUTOMATION WILL VARY AMONG ECONOMIES DUE TO DIFFERENT DEMOGRAPHICS, WAGE LEVELS, PRODUCTIVITY, AND GROWTH ASPIRATIONS

While automation at a global level can be a significant economic growth engine by helping reduce the growth gap created by a shrinking workforce, its effects will play out differently in different countries, depending on the demographic situation in each country, current productivity levels, wage levels, GDP growth aspirations, and adoption scenarios for automation.

As we have seen, countries with high shares of aging populations, such as Germany and South Korea, will have a more urgent need for the productivity boost that automation can provide. But countries with a range of demographic profiles and growth aspirations also face challenges and opportunities. We identify three groups of countries, each of which may be able to use automation to further national economic growth goals. The groups are advanced economies with aging or shrinking workforces, emerging economies with aging workforces, and younger emerging economies whose workforces are still growing and which have high aspirations for future economic growth.

Advanced economies with shrinking workforces could benefit rapidly from automation to compensate for demographic pressures on growth

Countries including Australia, Canada, France, Germany, Italy, Japan, South Korea, the United Kingdom, and the United States, with an aggregate annual GDP growth aspiration until 2030 of 1.8 percent, stand to benefit from automation in the medium term. These advanced economies face a deficit of full-time equivalents even to maintain current GDP per capita because of their aging populations. Automation could provide enough of a productivity boost for them to achieve projected GDP for the next few decades.

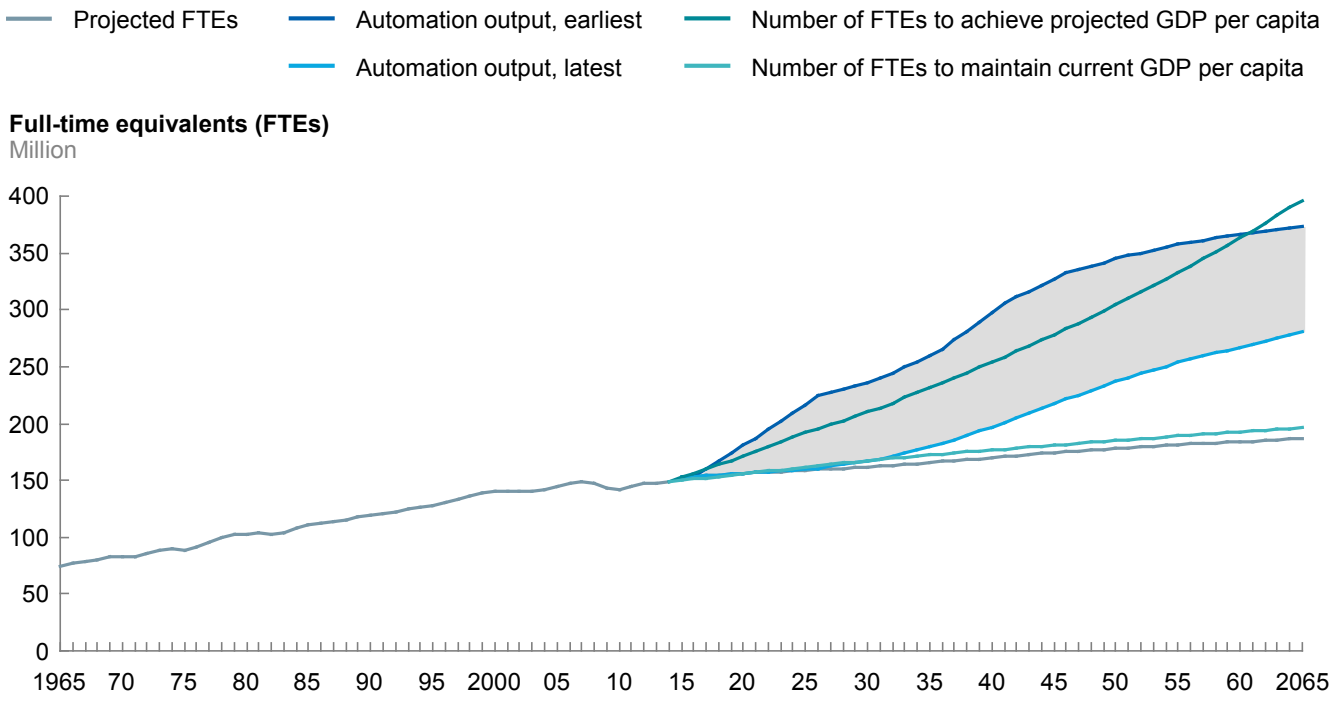
These countries have considerable incentives to accelerate the pace of automation by investing in research and development, encouraging the development of hardware and software solutions to integrate automation technology advances, and other measures that could make automation more economically feasible. This could more than compensate for the demographic changes that would otherwise likely slow down economic growth.

Exhibit 29 uses the United States as an example of this group. It shows that automation could make a significant contribution to the productivity increase that the United States needs to achieve GDP per capita growth. The United States faces a shortfall of around 15 million workers already by 2020 just to maintain current GDP per capita. Automation, if adopted early enough, could enable the United States not only to maintain GDP per capita, but also to attain the GDP per capita growth rate projected for the economy for the next several decades, despite the aging population.

[85] *Global growth: Can productivity save the day in an aging world?* McKinsey Global Institute, January 2015.

Exhibit 29

In the United States, automation can help achieve projected GDP per capita growth



NOTE: The "projected GDP per capita" scenario for the United States uses projections from McKinsey's Global Growth model, with GDP compound annual growth rate (CAGR) for 2015–65 of 1.9%, resulting in a productivity CAGR of 1.5%. The "maintain current GDP per capita" scenario assumes GDP will grow at the same rate as population (0.5% CAGR for 2015–65), resulting in a productivity CAGR of 0.1%. See technical appendix for details.

SOURCE: The Conference Board Total Economy database; International Labour Organisation; United Nations Population Division; McKinsey Global Institute analysis

Emerging economies with aging workforces will get a productivity boost from automation but will also need to find additional sources to maintain their growth trajectory

This category includes Argentina, Brazil, China, and Russia, which all face economic growth gaps as a result of projected declines in the working population. Their first distinguishing factor is that their current productivity is not sufficient to support GDP per capita over the long run. For these economies, automation could provide the productivity injection necessary just to maintain GDP per capita. However, to achieve a faster growth trajectory that is more commensurate with their developmental aspirations (GDP growth of 4.1 percent and GDP per capita growth of 3.8 percent), these countries would need to supplement automation with additional sources of productivity, such as process transformation and other technologies.

This grouping is not monolithic, and there are some divergences based on demographic and economic growth differences. Argentina, Brazil, and Russia, for example, are projected to have lower GDP per capita growth than China. Argentina and Brazil have younger populations than China and Russia; the median age is about seven years lower. They also have significantly faster-growing populations.

While these economies could receive a strong productivity boost from automation, their wage levels are lower than in the advanced economies we discussed above, and their overall adoption of automation may be slower as a result, since the business case for adoption may be less compelling. As we have seen, in these countries it could take longer for the cost of automation solutions, especially if they involve hardware, to make automation feasible when compared to the costs of human labor.

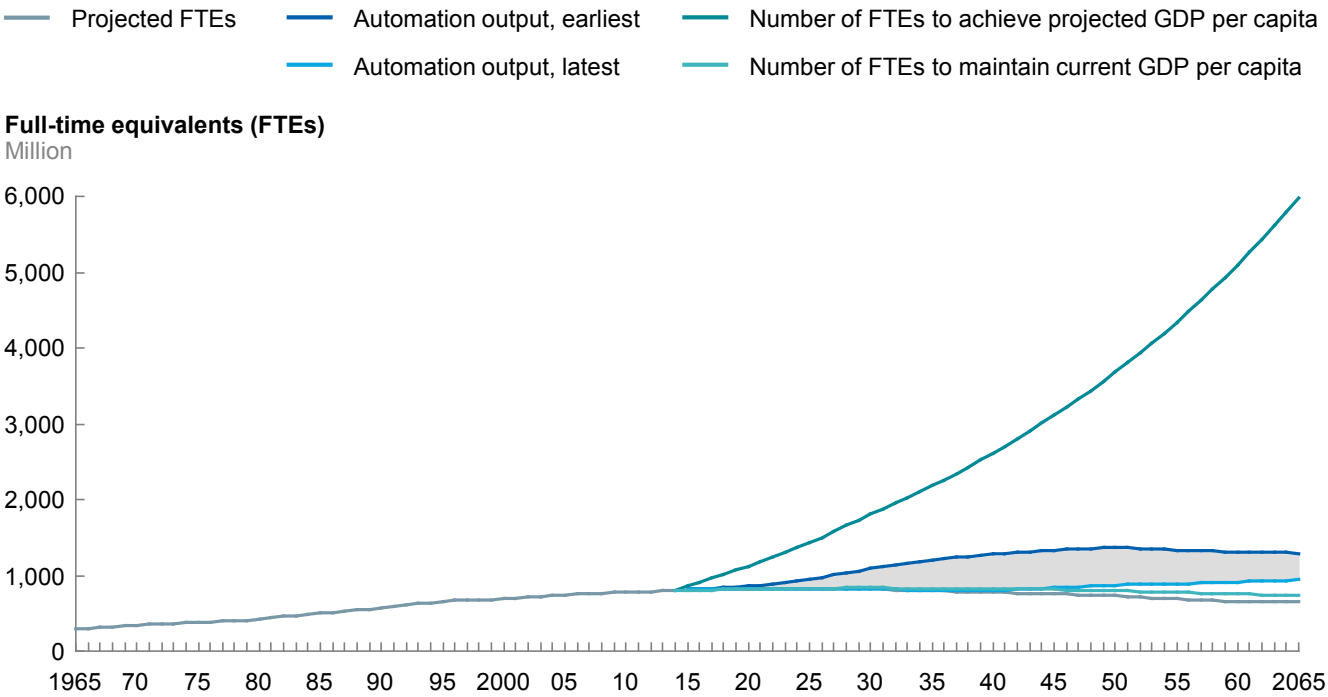
Policy measures including encouraging increased competition and the development of a high standard of technological literacy in the population at large could help speed the process of automation adoption. China, for example, already has the highest rate in the world for technology-enabled payment platforms; a recent report by market research firm Nielsen found that 86 percent of Chinese paid for online purchases with digital payment systems, double the global average.[86]

A second distinguishing factor for these economies that will affect the impact of automation is that their overall productivity levels tend to be relatively low compared with those of advanced economies. To capture the full multiplier effects from automation, and achieve their aspirations for a continued fast-growth trajectory, these countries will need to supplement automation with other levers to enhance productivity.

Exhibit 30 shows the example of China from this group of fast-growing emerging economies. China's population is aging rapidly, which means that in the longer term its working-age population will peak as early as 2024 and could shrink by one-fifth.[87] Within the next decade, its workforce will be short of the equivalent of about 600 million workers to attain the projected growth if it does not drive productivity improvements. Early adoption of automation could lessen this gap by about 100 million FTEs, but the country still faces a likely shortfall.

Exhibit 30

Automation can contribute to productivity growth in China, but its high projected GDP per capita growth requires additional productivity levers



NOTE: The "projected GDP per capita" scenario for China uses projections from McKinsey's Global Growth model, with GDP compound annual growth rate (CAGR) for 2015–65 of 4.0%, resulting in a productivity CAGR of 4.5%. The "maintain current GDP per capita" scenario assumes GDP will grow at the same rate as population (-0.2% CAGR for 2015–65), resulting in a productivity CAGR of 0.3%. See technical appendix for details.

SOURCE: The Conference Board Total Economy database; International Labour Organisation; United Nations Population Division; McKinsey Global Institute analysis

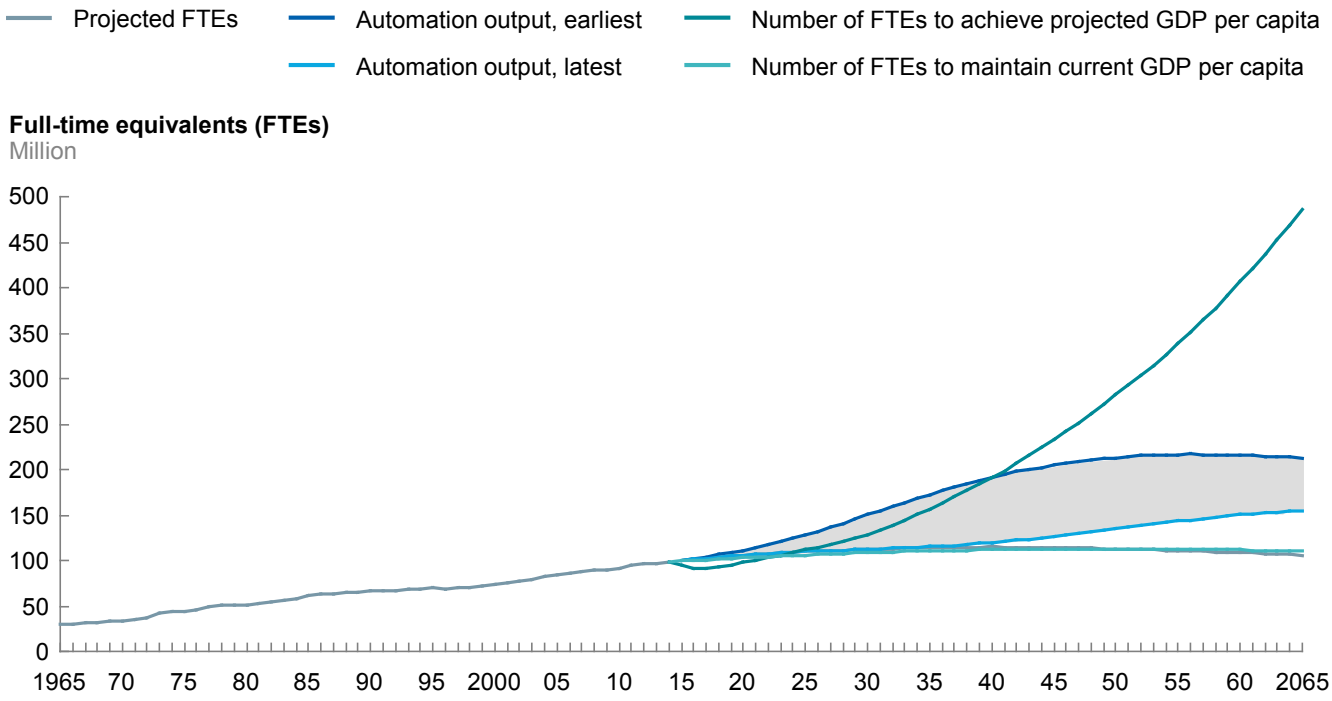
[86] *China maintains robust e-commerce growth*, Nielsen, March 2016

[87] *Global growth: Can productivity save the day in an aging world?* McKinsey Global Institute, January 2015.

In Exhibit 31, we highlight Brazil as another example in this group. The model shows that early adoption of automation could allow Brazil to meet its medium term GDP per capita growth expectations. But finding additional levers to accelerate Brazil's productivity growth would be beneficial in both the medium term, as the majority of the adoption scenarios show automation not providing sufficient economic growth to meet projected GDP per capita growth, and in the long term.

Exhibit 31

Automation of existing activities could help Brazil meet its medium-term GDP per capita growth aspirations, but additional productivity acceleration could be required



NOTE: The "projected GDP per capita" scenario for Brazil uses projections from McKinsey's Global Growth model, with GDP compound annual growth rate (CAGR) for 2015–65 of 3.3%, resulting in a productivity CAGR of 3.2%. The "maintain current GDP per capita" scenario assumes GDP will grow at the same rate as population (0.2% CAGR for 2015–65), resulting in a productivity CAGR of 0.1%. See technical appendix for details.

SOURCE: The Conference Board Total Economy database; International Labour Organisation; United Nations Population Division; McKinsey Global Institute analysis

Emerging economies with younger populations will get a boost from automation but will need other productivity gains to ensure sufficient longer-term growth

The third grouping we identify are emerging economies with younger populations. These include India, Indonesia, Mexico, Nigeria, Saudi Arabia, South Africa, and Turkey. Saudi Arabia is something of an anomaly in this group because of its high wages adjusted for purchasing power parity (see Box 6, "With a combination of strong population growth and high wages, Saudi Arabia is atypical"). These countries all have aspirations for high long-term growth, in order to lift living standards for the rising population. At the same time, these countries have strong population growth rates. The ratio of working to total population will peak in the 2050s (except in Turkey and Saudi Arabia, where it will peak early), ensuring they have the necessary workforce to maintain GDP per capita. Even so, in these countries, automation on its own will not suffice to meet the growth aspirations, and other productivity levers will be needed. Exhibit 33 shows how the productivity impact of automation could play out in Nigeria, which has the highest population growth rate of the group. Still, to meet the projected GDP per capita growth, it faces a shortfall of ten million workers in 15 years. Early adoption of automation could close this gap.

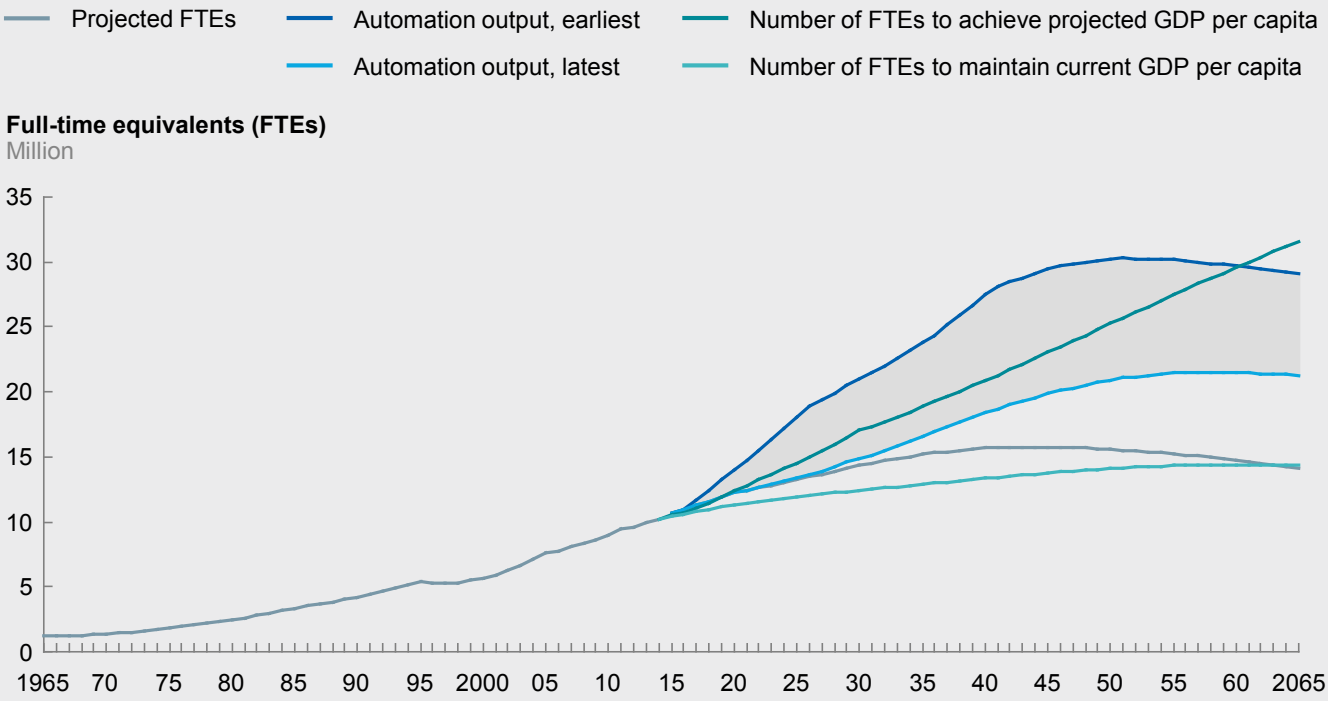
Box 6. With a combination of strong population growth and high wages, Saudi Arabia is atypical

Saudi Arabia and some of its neighbors in the Middle East are experiencing relatively slow growth, but they have both high wages, measured at purchasing power parity, and a growing workforce. Saudi Arabia, for example, has a demographic bulge: more than half the Kingdom's population is younger than 25, and by 2030 the number of Saudis aged 15 years and over will likely increase by about six million. Based on historical trends in participation, this upcoming demographic bulge could almost double the size of the Saudi labor force.[1] Its productivity growth of 0.8 percent between 2003 and 2013 was well below the average for its G20 peers.[2]

Automation could provide a considerable productivity boost to these countries, enough to meet GDP per capita growth aspirations. Moreover, automation will be economically feasible in these economies rapidly, because of their relatively high wage levels. The challenge for governments in these countries will be to create additional human jobs to employ the large cohort of young people who will reach working age in the near future. However, the ratio of working-age population to total population will peak in the 2030s, reversing the previous demographic dividend and making continued productivity gains more important (Exhibit 32).

Exhibit 32

Saudi Arabia's relatively high wage rates could drive early adoption, and its relatively young demographics put a premium on creating jobs



NOTE: The "projected GDP per capita" scenario for Saudi Arabia uses projections from McKinsey's Global Growth model, with GDP compound annual growth rate (CAGR) for 2015–65 of 2.2%, resulting in a productivity CAGR of 1.6%. The "maintain current GDP per capita" scenario assumes GDP will grow at the same rate as population (0.6% CAGR for 2015–65), resulting in a productivity CAGR of 0.1%. See technical appendix for details.

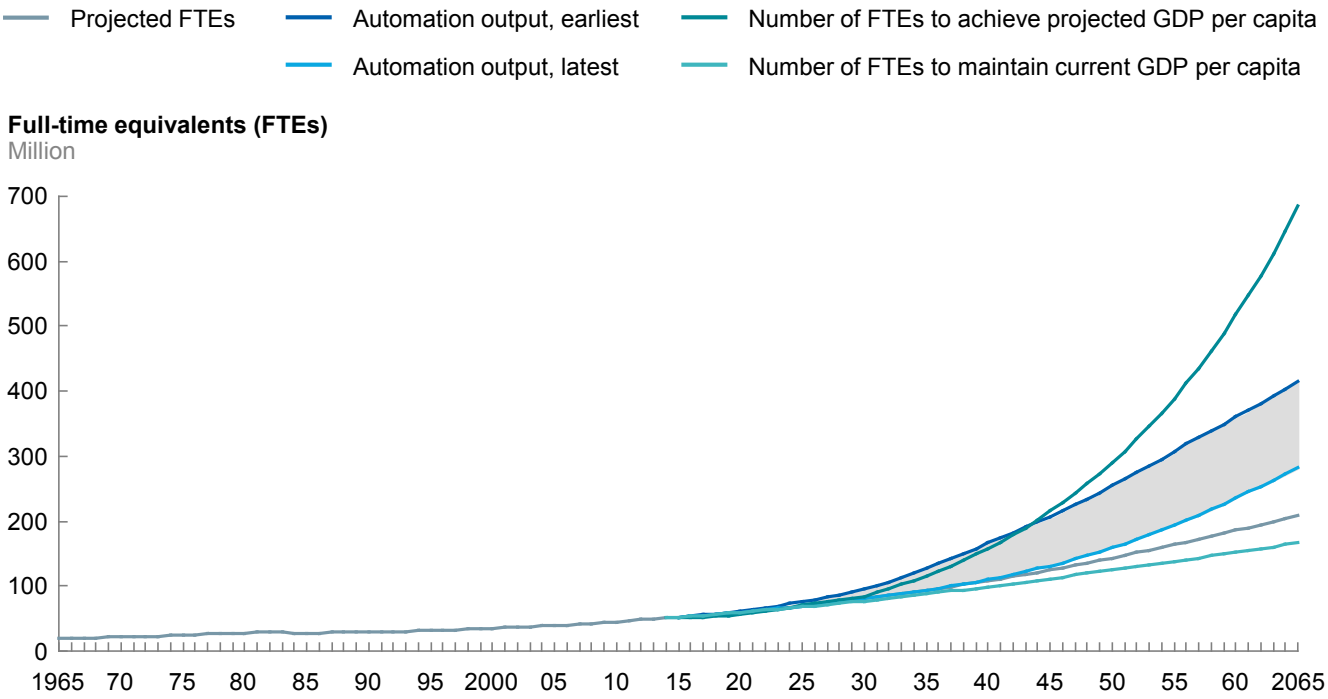
SOURCE: The Conference Board Total Economy database; International Labour Organisation; United Nations Population Division; McKinsey Global Institute analysis

[1] *Saudi Arabia beyond oil: The investment and productivity transformation*, McKinsey Global Institute, December 2015.

[2] Ibid.

Exhibit 33

In Nigeria, automation can contribute substantially to economic growth, but adding other means of productivity growth will likely be required to meet expectations



NOTE: The "projected GDP per capita" scenario for Nigeria uses projections from McKinsey's Global Growth model, with GDP compound annual growth rate (CAGR) for 2015–65 of 5.3%, resulting in a productivity CAGR of 2.4%. The "maintain current GDP per capita" scenario assumes GDP will grow at the same rate as population (2.4% CAGR for 2015–65), resulting in a productivity CAGR of -0.5%. See technical appendix for details.

SOURCE: The Conference Board Total Economy database; International Labour Organisation; United Nations Population Division; McKinsey Global Institute analysis

AUTOMATION'S IMPACT ON EMPLOYMENT COULD BE OF THE SAME ORDER OF MAGNITUDE AS PREVIOUS MAJOR STRUCTURAL ECONOMIC SHIFTS

A recurring question about automation is its effect on employment. Many forecasters paint a sometimes dire picture of what the adoption of automation could do for jobs, particularly blue-collar jobs. The World Economic Forum, for example, has predicted that more than five millions jobs could be lost to robots in 15 major developed and emerging economies over the next five years.[88]

The advent of large-scale automation in the workplace will undoubtedly alter the nature of the workplace, and the nature of work itself, as machines increasingly take over activities that were hitherto the domain of human workers. But to some extent, this is an old story. Telephone operators in the 1950s needed to physically connect switchboard plugs, but these jobs no longer exist today, as no physical capabilities are required to connect calls. Telex and telegraph operators are a dying profession. The typing pool that was a mainstay of office life in the 1950s and 1960s has not survived. In their place have come myriad new jobs born of the technological developments, from call center employees to IT help desk personnel. Personal assistants no longer take dictation, but monitor email.

[88] *The future of jobs: Employment, skills, and workforce strategy for the fourth Industrial Revolution*, World Economic Forum, January 2016. Other forecasters have made specific predictions about large-scale job losses related to automation or painted scenarios of a world without work. See Jeremy Bowles, *The computerization of European jobs*, Bruegel, July 2014; Martin Ford, *Rise of the robots: Technology and the threat of a jobless future*, Basic Books, 2015; and Carl Benedikt Frey and Michael A. Osborne, *The future of employment: How susceptible are jobs to computerisation?* Oxford Martin School, September 17, 2013.

Such anecdotal evidence is underscored by macroeconomic data. Positive gains have been reported in both productivity and employment in the United States in more than two-thirds of the years since 1929 despite the rapid onward march of technological development.[89] One-third of new jobs created in the United States in the past 25 years did not exist, or barely existed, 25 years ago.[90] Moreover, every three months about 6 percent of US jobs are destroyed by shrinking or closing businesses, while a slightly larger percentage of jobs are added.[91] This is not just a US phenomenon; findings from other countries indicate that these are global trends. For example, a detailed analysis of the French economy by McKinsey's French office, published in 2011, showed that while the internet had destroyed 500,000 jobs in France in the previous 15 years, it had created 1.2 million others, a net addition of 700,000, or 2.4 jobs created for every job destroyed.[92]

Will this pattern continue with automation, or could things be different this time? (See Box 7, "Is this time different?"). Certainly the scale and potential scope of the work activities that have the potential to be automated are very substantial indeed. Our model contemplates the possibility that hundreds of millions of workers will have to shift the activities they are paid to do.

Yet even this sort of large-scale structural economic shift over such a long period of time is not unprecedented. In the United States, for example, the share of farm employment fell from 40 percent in 1900 to 2 percent in 2000, while the share of manufacturing employment fell from 25 percent in 1950 to less than 10 percent in 2010 (Exhibit 34).[93] In both cases, the jobs that disappeared were offset by new ones that were created, although what those new jobs would be could not be ascertained at the time.

Whatever the net impact on employment, the nature of work will change with automation. There will be tighter integration between humans and machines than there is today, and this will increase overall efficiency, since machines will be more accurate with the activities that they take on. This will free up humans to perform tasks that use higher-level capabilities, especially those that require social and emotional ones.

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89 *Growth and renewal in the United States: Retooling America's economic engine*, McKinsey Global Institute, February 2011.

90 *Global growth: Can productivity save the day in an aging world?* McKinsey Global Institute, January 2015.

91 *Artificial intelligence, automation, and the economy*, Executive Office of the President, December 2016.

92 *Impact d'internet sur l'économie française: Comment internet transforme notre pays (The internet's impact on the French economy: How the internet is transforming our country)*, McKinsey & Company, March 2011.

93 Stanley Lebergott, "Labor force and employment 1800–1960," in *Output, employment, and productivity in the United States after 1800*, Dorothy S. Brady, ed., NBER, 1966; World Bank data; Mack Ott, "The growing share of services in the US economy—degeneration or evolution?" *Federal Reserve Bank of St. Louis Review*, June/July 1987.

Box 7: Is this time different?

Automation of human work activities has been occurring for at least the past two centuries, and while these technologies have automated a wide range of activities people had formerly been paid to do, new activities, occupations and jobs have been created. This has offset what would have become a situation of mass unemployment, had new demands for human labor not been produced.

But is this time different? Are we reaching a point where the pace and/or types of automating work activities will outstrip the global economy's ability to create new activities and jobs for people to be paid to do?

In some ways, this is an "evergreen" issue, in that these questions and concerns have accompanied the adoption of automation through history. Beyond the time of the Luddites in 19th-century Britain, John Maynard Keynes wrote about the "new disease" of technological unemployment during the Great Depression.[1] Over the years, many have speculated about decreasing demand for human labor as machines automate more work, including Keynes, in the same article from 1930 quoted above, and the 1966 US Commission on Technology, Automation and Economic Progress. But while the workweek has declined from working 10-18 hours per day, six days per week, during the Industrial Revolution to about eight hours per day, five days per week in the mid-20th century, it has not declined substantially since that point in many developed countries.

Some argue that there are factors suggesting that this time is different. Eric Brynjolfsson and Andrew McAfee describe an inflection point between the first machine age, based on the automation of physical tasks through mechanization, and a second machine age, based on the automation of cognitive tasks through digital technologies.[2] Digital technologies' basic capabilities, including computing power, storage capacity, and communications throughput, appear to be developing exponentially. For example, Moore's Law suggests that the computing power that can be purchased for $1 doubles roughly every two years. Chroniclers of "exponential technologies" such as Ray Kurzweil extrapolate out to a time when a computer will have the computing power of a human brain, and beyond, potentially pointing to a future in which, combined with the appropriate software, an "artificial general intelligence" could be created that rivals that of human beings. Others point to a dimension of human work described by the economists Daron Acemoglu and David Autor: between routine and non-routine work.[3] While much of the work that had historically been automated was routine (for example, what we describe in this report as predictable physical activities and the collection and processing of data), many of the examples of newer automation technologies that we find remarkable automate what we would have described as non-routine work. That includes driving cars in busy streets, or diagnosing disease.

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1 John Maynard Keynes, "Economic possibilities for our grandchildren," in *Essays in Persuasion*, Macmillan, 1933. The essay is available online at www.econ.yale.edu/smith/econ116a/keynes1.pdf.

2 Erik Brynjolfsson and Andrew McAfee, *The second machine age: Work, progress, and prosperity in a time of brilliant technologies*, W. W. Norton & Company, 2014.

3 Daron Acemoglu and David H. Autor, "Skills, tasks, and technologies: Implications for employment and earnings," in *Handbook of Labor Economics*, volume 4B, David Card and Orley Ashenfelter, eds., Elsevier, 2011.

Box 7: Is this time different? (continued)

However, the labor market has until now always adapted to the replacement of jobs with capital, with price effects tending to balance the forces of automation and creating new complex tasks for people to be paid to do. The December 2016 US White House report on artificial intelligence and automation states: "Recent research suggests that the effects of AI on the labor market in the near term will continue the trend that computerization and communication innovations have driven in recent decades… The economy has repeatedly proven itself capable of handling this scale of change, although it would depend on how rapidly the changes happen and how concentrated the losses are in specific occupations that are hard to shift from."[4] To support some of the assumptions in our modeling analyses, we argue that many of the factors affecting the pace and extent of automation adoption, such as the engineering of solutions to specific problems, and particularly the non-technical organizational change management, regulatory and acceptance dynamics around technology adoption, have not changed.

However, changing other assumptions in our model could lead to significantly different outcomes. For instance, our assumptions on the time required to develop capabilities and integrate and customize them into solutions that solve specific problems assumes that these activities will primarily be performed by people. But in a world where machines can teach themselves, these time frames could be considerably different from our assumptions.

We also only analyze the automation of current work activities at the performance levels at which humans currently perform them. If machines can perform these tasks at significantly higher levels, and/or other new productive activities, then productivity growth could accelerate even faster than we modeled. Similarly, we modeled workers displaced by automation returning to the workforce at the productivity of workers in 2014; if they return at higher levels of productivity (for example, at the average level of productivity of workers at the time they are displaced), then overall productivity growth will also accelerate. Could this lead to a surplus of labor? This would depend on the economy's ability to create new and more things to pay people to do.

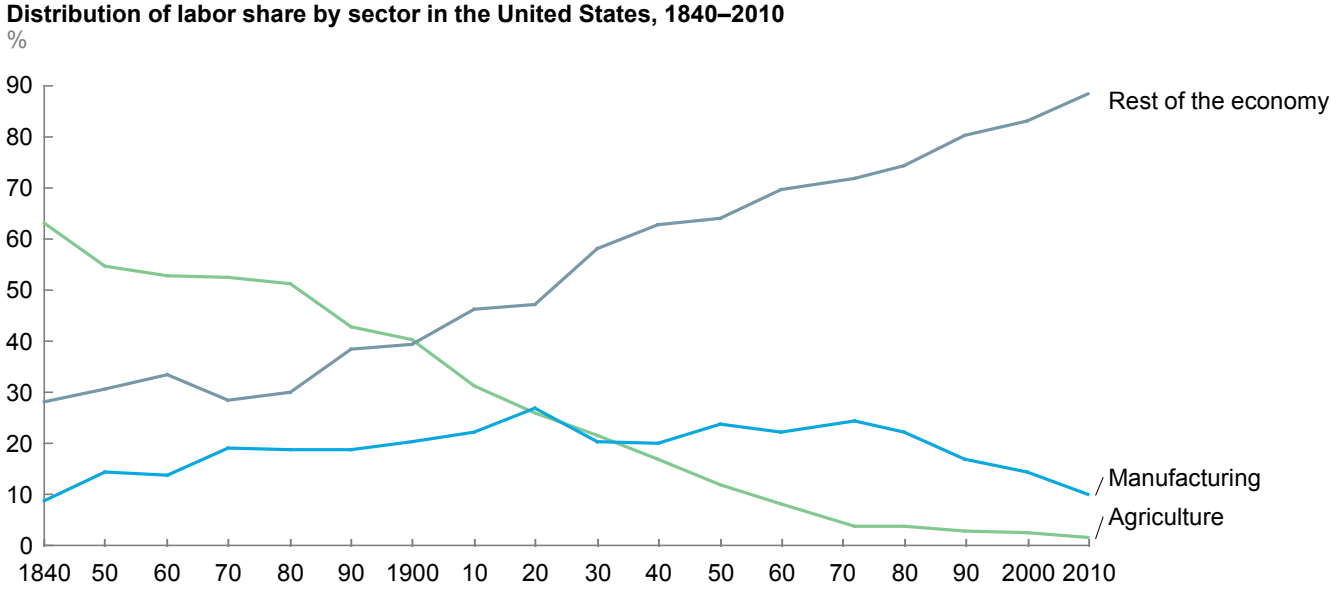
Is this time different? We can't definitely say—but the question is a familiar one.

[4] *Artificial intelligence, automation, and the economy*, Executive Office of the President, December 2016.

Exhibit 34

Employment in agriculture has fallen from 40 percent in 1900 to less than 2 percent today

Distribution of labor share by sector in the United States, 1840–2010



SOURCE: Stanley Lebergott, "Labor force and employment 1800–1960," in *Output, employment, and productivity in the United States after 1800*, Dorothy S. Brady, ed., NBER, 1966; World Data Bank, World Bank Group; FRED: Economic Research, Federal Reserve Bank of St. Louis; Mack Ott, "The growing share of services in the US economy—degeneration or evolution?" *Federal Reserve Bank of St. Louis Review*, June/July 1987; McKinsey Global Institute analysis

AUTOMATION COULD CHALLENGE SOME CONVENTIONAL BELIEFS ABOUT THE GLOBAL ECONOMY AND PATHS TO PROSPERITY

The advances in automation we have outlined and their potential impact on national economies could upend some prevailing models of development and challenge ideas about globalization. Among other possible repercussions, it could skewer conventional wisdom about the economic advantages of having a high birthrate. Low-cost labor may lose its edge as an essential development tool for emerging economies, as costs of automation fall. And these economies, in turn, will have new opportunities to leapfrog into higher-value manufacturing and services—including IT—that will enable them to compete head-on with advanced economies. Automation could also accelerate the diminishing of trade of physical goods that began a decade ago, as digital cross-border flows consolidate their pre-eminence.

Automation could reverse a demographic dividend for economies

The country scenarios we have outlined above could overturn ideas about the relationship between economic growth and population growth. The declining fertility rates and aging trends that have taken hold in a broad range of countries including China, Germany, Italy, and Russia have long been viewed as harbingers of weaker economic growth in the future—and a major policy challenge. The aging and shrinking of the workforce is unprecedented in modern history, and one of its consequences is that the number of retirees will likely grow more than twice as fast as the labor pool, leaving fewer workers to support the elderly.[94] Conversely, countries with a high birthrate and a growing working-age population were viewed as having an opportunity to achieve more rapid GDP growth, as they could build future growth on the twin pillars of productivity and employment growth.

[94] *The world at work: Jobs, pay, and skills for 3.5 billion people*, McKinsey Global Institute, June 2012.

Automation could help change that scenario. Countries experiencing population declines or stagnation will be able to make use of it to help maintain living standards even as the labor force wanes. Meanwhile, countries with high birthrates and a significant growth in the working-age population may have to worry about where new jobs will come from in a new machine age. This is especially the case for high-income and low-growth countries, including some in the Middle East.

The stakes are high because of the sheer numbers of people who have lifted their living standards as a result of countries following the classic developmental path—and the millions more who still hope to do so. In India, the impact of automation on employment could affect working hours of the equivalent of 220 million people; in China, that rises to 380 million full-time equivalents.

Chinese companies still have low levels of automation overall, although they are moving to ramp up. There are only 36 robots per 10,000 Chinese manufacturing workers, about half the average of all advanced economies and about one-fifth the US level.[95] Auto factories are less than 30 percent as automated as US plants, and food processing is only about 12 percent as automated as US food processing.[96] This gap reflects the cost of Chinese manufacturing labor, which has risen but remains low by the standards of advanced economies. The average manufacturing worker makes about 10 percent of the average US manufacturing wage, for example. Our research finds that most Chinese manufacturers are not yet able to realize the maximal value from robots due to a production process that is less than optimal. Chinese companies may adopt a hybrid model that mixes the speed and precision of automation with the flexibility of human labor.

Low-cost labor: No longer a development panacea?

Starting already in the 1880s in Japan, country after country around the world including South Korea, Taiwan, and most notably China, has followed a familiar pattern of development. A combination of low-wage agriculture and manufacturing—at times often backed by protectionist policies to encourage import substitution and boost exports—creates jobs and swells household income. As workers become more productive and households more prosperous, manufacturing moves up the value chain, producing higher quality products. Country dwellers flock to cities to join this industrialization wave, creating urban pockets of consumers with disposable income that helps generate greater prosperity. This trend has been driven by a huge influx of 1.2 billion people joining the global labor market between 1980 and 2010, and it has brought millions out of poverty. In 1990, about 23 percent of the world's population belonged to the "consuming class," by which we mean that they earned more than $10 per day. In 2010, that share had risen to 36 percent of the global population, and we project it will exceed 50 percent by 2025.[97]

That labor-intensive economic development model is still largely intact and is being followed by countries from India to South Africa. For countries still stuck in poverty, including in sub-Saharan Africa, it remains the obvious path to prosperity. But in the new world that is taking shape, low-cost labor may lose some of its edge as an essential developmental tool for countries, as automation drives down the cost of manufacturing globally. Indeed, research by the Harvard economist Dani Rodrik suggests that a "premature deindustrialization" is already taking place in some emerging economies, although he ascribes that more to trade and globalization than to technological progress.[98]

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95 *The China effect on global innovation*, McKinsey Global institute, October 2015.

96 Ibid.

97 *Global growth: Can productivity save the day in an aging world?* McKinsey Global Institute, January 2015.

98 Dani Rodrik, *Premature deindustrialization*, NBER working paper number 20935, February 2015.

As we have seen, the type of activities most susceptible to automation includes physical activity or operating machinery in a predictable setting—in other words, highly routine work. A number of occupations in manufacturing sectors that use low-cost labor fit into this category, such as sewing machine operators, who have a 98 percent automation potential. Agriculture, too, has a high automation potential because much of its activity is both physical and predictable, and thus replaceable by machines. The speed of adoption of automated technology depends in part on the size of the firms. For example, in India, where much farming is on a small-scale family subsistence model, changing to larger-sized farms would sharply raise the automation potential.

For advanced economies that have lost manufacturing jobs over the past decades because of competition from lower-cost labor and the buildup of supply chains elsewhere, the drive to automation may end or even reverse the outflow. The wage gap between advanced and emerging economies is wider in manufacturing than for other sectors. At the same time, companies in advanced economies often have a greater ability to fund the capital expenditure that is needed to build highly automated manufacturing plants.

That does not mean jobs will flow back in large numbers, since only a very small part of manufacturing value added is driven by labor cost, and any "re-onshoring" that does take place will likely happen in highly automated plants. Moreover, for companies in advanced economies, the business case for automation is not simple: hardware and software can be costly, and integrating them successfully is laborious. But machines also have some clear advantages: they can run continuously and do not require large human resources departments. Operations are easier to manage if they are next door, which makes oversight and shipping easier than if operations were halfway around the world. Politically and from a public relations standpoint, too, it can be advantageous to be seen as a local stalwart.

New opportunities for higher-value manufacturing and services through automation

Growing use of automation across sectors and within sectors raises the prospect that some countries could leapfrog in the future to become active in industries where they are now weak or have little presence and either no infrastructure base or one that is aging and technically obsolete. For example, Saudi Arabia and Iran have aspirations to build up an automotive industry to serve not just the domestic market but also the wider Middle East region. They both have domestic supplies of raw materials, such as iron ore and bauxite, and plentiful energy; deploying automation technologies could help them leapfrog into state-of-the-art manufacturing. In Russia, where the number of employees will likely decrease by 30 percent over the next half century as a result of a declining birthrate, automation could compensate for the smaller workforce and revitalize growth in manufacturing sectors. New technologies and integrated solutions might reduce capital expenditure, benefiting emerging economies with limited resources. They also potentially provide the ability for emerging economies to create economies of scale.

Emerging economies could gain an edge in some service sectors, including health care and social assistance, IT, and professional, scientific, and technical services. That is because the gap in wages between countries for these services is less pronounced than it is for manufacturing, and the cost of the software needed to compete on a global scale is much lower.

Automation could accelerate the diminishing of physical trade

What we now can see as the heyday of globalization, the 20-year period that began in the mid- to late 1980s, the global flows of goods, services, and finance grew rapidly, outpacing GDP growth. Since the global financial recession in 2008 and slow recovery, however, that rapid expansion has stopped in its tracks. Growth in global goods trade has flattened, trade in services has posted only modest growth, and financial flows have fallen sharply. At the same time, data flows have soared, with cross-border bandwidth growing 45 times larger since 2005. Data flows now account for a larger impact on of global GDP than does global trade in goods.[99]

Automation could to some extent push this trend further, as companies rely less on traditional shipping methods and more on digital transactions and exchanges. For example, 3D printing, if widely adopted by global manufacturers, could reduce global trade volumes as more products are "printed" where they are consumed. There are already examples of this at work, such as GE Aviation, which is beginning to use 3D printing to produce fuel nozzles for its new Leap engine.[100] A fuel nozzle made the traditional way consists of 20 components, with a supply chain that spans countries. 3D printing allows the company to produce best-quality nozzles in one piece, at one location, eliminating the need to ship intermediate parts across borders.

At the same time, the rise of digital platforms such as Alibaba, Amazon, and eBay changes the economics of doing business across borders, bringing down the cost of international interactions and transactions. These platforms create markets and user communities with global scale, providing businesses in advanced and emerging economies alike with a huge base of potential customers and effective ways to reach them. Companies based in developing countries can overcome constraints in their local markets and connect with global customers, suppliers, financing, and talent far more easily than they ever could.[101]

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Automation can quickly become a new engine for the global economy at a time when the working-age population in numerous countries is stagnant or falling and productivity growth is struggling to compensate. Whatever their economic structure, wage levels, growth aspirations, or demographic trends, countries around the world could benefit from adopting automation to maintain living standards and help meet long-term growth aspirations. The rapid development and growing adoption of automation technologies will create myriad new opportunities even as they likely disrupt the world of work and challenge long-held conventions about the global economy and paths to prosperity. In order to make the most of the potential offered by automation and, at the same time, manage its consequences on companies, national economies, and workers around the world, policy makers, business leaders, and men and women everywhere will need to think through the implications that these new technologies will bring and prepare for significant changes. In our final chapter, we discuss how stakeholders around the world can position themselves to benefit fully from automation's potential while avoiding its pitfalls.

[99] *Digital globalization: The new era of global flows*, McKinsey Global Institute, February 2016.
[100] Ibid.
[101] *Playing to win: The new global competition for corporate profits*, McKinsey Global Institute, September 2015.

6. PREPARING FOR DISRUPTION

Automation's challenge for policy makers, business leaders, and workers everywhere is a formidable one: how to capture the positive effect on the global economy, at the same time as navigating what is likely to be a complicated period ahead, one with potentially epochal social, economic, and employment repercussions.

At a time of sluggish GDP growth and weak productivity gains—and when demographic trends are starting to work against growth in a broad range of countries—automation could serve as an unforeseen boon to the world economy. Yet anxieties about lost jobs and reduced incomes are already creating a backlash against globalizing and modernizing trends, especially in advanced economies, influencing election outcomes in several countries. Ever since the Industrial Revolution, evolving technologies have aroused fears as well as excitement. The risk that automation could become a scapegoat is real.

As already noted, the public debate over automation takes place against a backdrop of a growing gap in incomes and employment prospects of high-skill and low- and middle-skill workers.[102] The share of national income that is paid to workers, the so-called wage share, has been declining in many advanced economies even as productivity has risen, suggesting a disconnect between productivity and incomes, which automation could potentially exacerbate further. The wage-share decline is due in part to the growth of corporate profits as a share of national income, as a result of rising capital returns to technology investments, lower returns to labor from increased trade, rising rent incomes from homeownership, and increased depreciation on capital.[103]

Moreover, there is already a significant mismatch of skills in the global workforce, with high levels of youth unemployment and, at the same time, a shortage of job seekers with critical skills. Overcoming this mismatch is a complex undertaking that requires close cooperation among education providers, governments, and businesses.[104]

Uncertainty about the timing of automation adoption and its potentially variable impact from sector to sector, from country to country, and from workplace to workplace, make the challenge of preparing for it even more complex. Yet preparation is both possible and necessary, within the business world, at a policy level, and for individuals. Automation technologies are advancing rapidly, and those who harness them effectively and take the lead in their sectors will gain a competitive advantage.[105] It is never too early to think through strategic options and appropriate responses.

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[102] See the discussion of technical change and skills in Chapter 4.

[103] While overall spending on capital goods has been weak, there has been considerable investment in information technology, whose prices have declined. See Loukas Karabarbounis and Brent Neiman, *The global decline of the labor share*, NBER working paper number 19136, June 2013; Loukas Karabarbounis and Brent Neiman, *Declining labor shares and the global rise of corporate saving*, NBER working paper number 18154, June 2012; and *How CBO projects income*, Congressional Budget Office (CBO), July 2013. See also, *Poorer than their parents? Flat or falling incomes in advanced economies*, McKinsey Global Institute, July 2016.

[104] For a detailed discussion of the education to employment transition, see *Education to employment: Designing a system that works*, McKinsey Center for Government, January 2013. See also, *A labor market that works: Connecting talent with opportunity in the digital age*, McKinsey Global Institute, June 2015.

[105] For details of how companies that are leaders in digitization increase profit margins and raise productivity, see *Digital America: A tale of the haves and the have-mores*, McKinsey Global Institute, December 2015.

AUTOMATION WILL PROVIDE SIGNIFICANT OPPORTUNITIES FOR COMPANIES TO CAPTURE VALUE, BUT IT WILL HEIGHTEN COMPETITION AND REQUIRE CHANGED BUSINESS ROLES AND WORKFLOWS

Capturing the full opportunities offered by automation including both the labor substitution and other performance benefits is likely to give companies a competitive advantage, but doing so will likely require them to conduct a thorough review of corporate activities and potential overhaul of business processes and workflows.

Automation will enable new forms of competitive advantage, but it will also require companies to raise their game just to keep up

There are many opportunities for companies to take advantage of the potential of automation to seek competitive advantage. Automation of various activities can improve the performance of almost any business process, as we noted in our case studies in Chapter 3. Certainly, automation can be used to transform the costs of a process by reducing labor costs, for example when end-to-end digitization is used to create straight-through processing of a transactional process. As we have also documented, automation can not only enable a reduction in labor costs, it can also bring a range of other benefits related to performance improvements, such as greater throughput, improved reliability, raised quality, better safety, and other gains. Straight-through processing of financial transactions, for instance, is usually faster than the manual process it replaces, and reduces the number of errors introduced into the process.

Thus, any of the benefits that automation can unlock could become a basis of competition. An industrial company that is able to ensure significantly lower downtime than its competitors by automated monitoring and predictive maintenance of its equipment can compete on this basis of better reliability. A consumer company that can provide faster delivery and 24x7 customer service, through automation in its supply chain and contact centers, can compete on the basis of being more responsive to its customers. Automation can also enable companies to create new products, services and/or business models, for example, a professional services company that is able to provide customized advisory services to small and medium-sized businesses, or even consumers, through an automated conversational interface.

Some of the strategic capabilities that automation can unlock are more subtle and wide-ranging than improving the performance of a particular process or offering. Some forms of automation, for example those that are based on machine learning techniques such as deep learning, improve their performance over time when they have access to more data. Companies that are able to create platforms with increasing returns to scale can create network effects that result in winner-take most dynamic. Machine learning on user data allows the platform to become more compelling to users, which in turn generates more data.[106] We have seen these types of dynamics in online search platforms, social media platforms, media delivery platforms, and increasingly platforms that support activities in the physical world, such as platforms for Internet of Things data, healthcare, and travel and transportation.

Automation could also unlock the otherwise unlikely combination of scale and agility, with the ability to instantly propagate changes across an entire organization. When an organization's activities are controlled by automatic systems, modifying the behavior of the enterprise can be accomplished by software download, rather than an extensive change management program. When automation is used to augment human management, traditional organizational orthodoxies, such as about spans of control, can be challenged. For example, Uber takes advantage of automation for coordination, and has only about one

[106] Michael Chui and James Manyika, "Competing at the digital edge: Hyperscale businesses," *McKinsey Quarterly*, March 2015.

human manager per 1,000 drivers compared with a typical limousine company that has about one manager per 20 to 30 drivers. However, greater scale and speed also means that the effects of negative changes are amplified. And these are not the only challenges that automation could bring to businesses. From a technology standpoint, as software and data underlie nearly all new automation technologies, cybersecurity issues become more critical than ever.

Strategically, automation can also heighten competition, enabling startups or firms from other sectors to encroach on new turf and exacerbating a growing divide between technological leaders and laggards in every sector.[107] At the same time automation can support increasing scale, it also can provide the leverage that enables smaller companies to compete with much larger firms. When the basis of competition using automation is algorithms and data, the raw materials of competition are more readily accessible, through the cloud and open data. For example, we have seen the advent of new competitors in the media and game sectors deploying automation tools to quickly gain the reach of much more established players.

The fact that automation displaces human work activities creates a set of real challenges for companies that deploy it. Worker displacement creates the potential for labor unrest, and the size and scope of retraining/placement programs, whether put in place by companies or others, will have to mirror the size and scope of automation programs. The effective use of automation requires the transformation of processes, changing what people do, even those that are not made redundant by automation. In general, workflows will change, and new roles will emerge, such as that of robot trainer or exception handler.

Companies embracing automation could experiment and map areas of likely impact, even as they focus on workplace changes and new skills for workers

Companies who recognize both the opportunities and threats of automation to competitiveness will engage and embrace the potential that these technologies represent, prioritizing a set of active experiments to start climbing the learning curves earlier rather than later. To help diagnose where automation could most profitably be applied to improve performance, business leaders may want to conduct a thorough inventory of their organization's activities and create a heat map of where automation potential is high. Business processes shown to have activities with high automation potential could be reimagined under scenarios where they take full advantage of automation technologies (rather than mechanically attempting to automate individual activities using current processes). The benefits and feasibility of these automation-enabled process transformations could then be used to prioritize which processes to transform using automation technologies.

Business leaders and their organizations will also need to become more knowledgeable about the evolution of the technologies themselves, understanding the art of the possible, and the potential for the future, in order to best position their enterprises to take advantage of automation. This is not just "book knowledge" that comes from reading about technologies, or visiting global centers of innovation, but practical knowledge that comes from devoting some resources to continually and purposefully experimenting with technologies on real problems, and then scaling those that demonstrate promise.

Perhaps the most vital component to being successful at deploying automation is the hard work that has to be done to prepare and adapt human capital to work in complementary ways with technology. As our activity-based analysis has shown, almost every role will change, and every workflow eventually will be transformed. Workers will have to be continually retrained as the work activities that they do, to work alongside machines,

[107] This is already happening with digital technologies. See ibid.

continue to evolve. Others will have to be redeployed, potentially to other positions in the economy, and businesses have a role to play in aiding these transitions. This will require not only changes in skills, but also changes in mindsets and culture, in a world where work activities continue to change, and "co-workers" include not only other people, but also machines.

FOR POLICY MAKERS, AN EMBRACE OF AUTOMATION COULD GO HAND IN HAND WITH MEASURES TO SUPPORT LABOR DEPLOYMENT

Policy makers must recognize the pressing need for productivity acceleration to compensate for demographic aging shifts in order to enable GDP per capita growth. Automation technologies can provide a major contribution to accelerating productivity growth. Thus there are two broad categories of issues for policy-makers to consider. First, how can we accelerate the development and deployment of automation to generate greater growth in productivity? Second, how can we support the redeployment to other productive activities of workers whose activities are automated?

Policy makers can accelerate early development and adoption of automation technologies

Early adoption of automation could benefit from policy support, both in regard to the technology development and for its deployment. This support could include investments in developing the technologies themselves, including funding basic research and support for commercialization, as well as supporting investments in digitally enabled infrastructure for automation.

Investment in enabling infrastructure for automation adoption could be an early priority, especially for emerging economies that may not be as digitally enabled as some advanced economies. In general, large-scale automation will require substantial investment, and the tax and other treatment of this investment could enable—or hinder—the adoption of automation technologies. For regulators, automation can pose challenging issues for safety and liability; for example, in the case of self-driving vehicles, who could be held liable for accidents—the automaker, the owner, or the algorithm creator? Thoughtful regulatory dialog and policy making will be important to ensure that the benefits of automation are achieved while protecting other societal concerns.

Engaging a broader societal dialog about automation, the need for productivity growth, and shifts in labor markets is another role that policy-makers can play. Deployment of some technologies could face concerted opposition from unions or other labor organizations over concerns about the employment impact. Governments will need to find cogent answers and coherent policies to engage in these debates

Exposing and stimulating the work that needs doing

Governments are often not particularly able by themselves to anticipate the types of jobs that could be created, or new industries that will develop (and they are not alone in this limitation). However, they are well positioned to catalyze dialogues about what work needs doing, and the grand societal challenges that require more attention and human effort.[108] The 1966 US Report of the National Commission on Technology, Automation and Economic Progress devoted multiple chapters to "Unmet Human and Community Needs," including sections on education, healthcare, urban transportation, air pollution, water resources, housing, and international development, all of which seem as relevant in this era as they were 50 years ago.[109] Perhaps a similar report today would add caring for the elderly to the list, as we have documented the demographic effects of aging.

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[108] Tim O'Reilly, "Don't replace people. Augment them," Medium.com, July 17, 2016.

[109] *Technology and the American economy: Report of the National Commission on Technology, Automation, and Economic Progress*, US Department of Health, Education, and Welfare, 1966.

While policy-makers might not be able to predict the new activities and occupations that can be created, they can help create the conditions under which innovation in the use of human labor becomes more likely. Governments could also encourage new forms of technology-enabled entrepreneurship. Digital technology itself can enable new forms of entrepreneurial activity. Workers in small businesses and self-employed occupations can benefit from higher income earning opportunities. A new category of knowledge-enabled jobs will become possible as machines embed intelligence and knowledge that low-skill workers can access with a little training. In India, for example, Google is rolling out the internet Saathi (friends of the internet) program in which rural women are trained to use the internet and then become local agents who provide services in their villages through internet-enabled devices. The services include working as local distributors for telecom products (phones, SIM cards, and data packs), field data collectors for research agencies, financial-service agents, and para-technicians who help local people access government schemes and benefits through an internet-based device. There is a need for these services in rural India where broad internet reach and digital literacy are still low, but where an increasing number of services are being provided online. Google's program aims to create more than 50,000 internet Saathis who will provide services to more than 50 million households in rural India.[110]

Addressing wages, skills gaps, and labor market mismatches

One of the challenges of the new era will be to ensure that wages are high enough for the new types of employment that will be created, to prevent continuing erosion of the wage share of GDP, which has dropped sharply since the 1970s.[111] While some governments may be tempted to look for ways to slow automation adoption, out of concern for possible employment effects, such moves could prove counterproductive, holding back productivity without protecting jobs durably.

Automation could exacerbate a skills gap, even as it touches all occupations. There is already a growing divide in income advancement and employment opportunities between high-skill workers and those who are low- and medium-skill. In the past two decades, there has been a clear pattern of consistent job growth for high-skill workers and little or no growth for low- and middle-skill ones. For example, in 1981, college-educated workers in the United States earned a 48 percent wage premium over high school graduates. By 2005, that premium had risen to 97 percent—in other words, an American college graduate earns almost twice as much as a high school graduate.[112] The growing gap between productivity and wages is not new, but automation could accelerate the process. In its 2016 report on automation, the White House noted that the trend toward skill-biased change brought about by computerization and communications innovations is likely to continue in the decade ahead as a result of artificial intelligence's effects on the labor market.[113]

To address this gap, policy makers could work with education providers to improve basic skills through the schools system and put a new emphasis on capabilities that are among the most difficult to automate, including creativity, understanding human emotions, and managing and coaching others. For people who are already in the workforce, they could intervene to help workers develop skills best suited for the automation age. For example, many economies are already facing a shortage of data scientists and business translators.[114] Governments working with the private sector could take steps to ensure that such gaps

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[110] *India's technology opportunity: Transforming lives, empowering people*, McKinsey Global Institute, December 2014.

[111] *Poorer than their parents? Flat or falling incomes in advanced economies*, McKinsey Global Institute, July 2016.

[112] David Autor, "Skills, education, and the rise of earnings inequality among the 'other 99 percent,'" *Science*, volume 344, issue 6186, May 2014. See also *Poorer than their parents? Flat or falling incomes in advanced economies*, McKinsey Global Institute, July 2016.

[113] *Artificial intelligence, automation, and the economy*, Executive Office of the President, December 2016.

[114] *The age of analytics: Competing in a data-driven world*, McKinsey Global Institute, December 2016

are filled, with new education and training possibilities established rapidly and prioritized. They could also foster the growth of technology-enabled solutions for the labor market that improve matching and access to jobs, such as online talent platforms.[115] As automation reshapes the workplace, independent work could become increasingly important, and policy makers will want to address issues such as benefits and variability that these platforms can raise.

Furthermore, while important work that needs doing might be identified, there is a possibility of market failures in the wages that might be paid for that work, a situation for which public policy interventions might be appropriate.

Rethinking social support

Full or partial automation will result in labor displacement, and it will be important to support workers as they transition from one set of activities to another. As work evolves at higher rates of change between sectors, locations, activities, and skill requirements, many workers may need assistance in adjusting to the new age. This could involve providing support during transitional periods, for example retraining or income support. While our modeling suggests a higher likelihood of labor shortages than labor surpluses, there might be people whose skills and capabilities are mismatched to the work that needs doing, or where wages are put under pressure by specific increases in labor supply (for example, within a geography, for workers with particular skills, in specific industries). In these cases, adapted social safety nets could help provide support. Various ideas have been considered, including work sharing, negative income taxes, and universal basic income (see Box 8, "When some old policy ideas are new again").

FOR WORKERS, AUTOMATION WILL CHANGE MANY WORK PROCESSES AND REQUIRE A CLOSER COLLABORATION WITH TECHNOLOGY

Regardless of the longer-term implications, in the short to medium term, men and women in the workplace will need to engage more comprehensively with machines as part of their everyday activities. Tighter integration with technology will free up time for human workers including managers to focus more fully on activities to which they bring skills that machines have yet to master. This could make work more complex, and harder to organize, with managers spending more time on coaching.

As young people in particular make education and career choices, it will be important for them to be made aware of the factors driving automation in particular sectors, to help them identify the skills that could be useful for them to acquire from a labor-market perspective, and what activities will be complements of activities that are likely to be automated.[116]

High-skill workers who work closely with technology will likely be in strong demand. Those involved in developing and deploying automation technologies will have many opportunities. In addition, workers who are paid to do activities that are complements of automation will also find themselves in an advantageous position, as Brynjolfsson and McAfee have described it, racing with the machines rather than racing against the machines.[117] These and other workers may be also able to take advantage of new opportunities for independent work as the corporate landscape shifts and more project work is outsourced by big companies. Low-skill workers working with technology will be able to achieve more in terms of output and productivity but may experience wage pressure given the potentially larger supply of similarly low-skill workers.

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[115] *A labor market that works: Connecting talent with opportunity in the digital age*, McKinsey Global Institute, June 2015.

[116] Erik Brynjolfsson and Andrew McAfee, *The second machine age: Work, progress, and prosperity in a time of brilliant technologies*, W. W. Norton & Company, 2014.

[117] Ibid.

Education systems will need to evolve for a changed workplace, with policy makers working with education providers to improve basic skills, with a new emphasis on topics such as creativity, emotional intelligence, and leading and coaching others. For all, developing agility, resilience, and flexibility will be important at a time when everybody's job is likely to change to some degree.

Finally, automation will create an opportunity for those in work to make use of the innate human skills that machines have the hardest time replicating: social and emotional capabilities, providing expertise, coaching and developing others, and creativity. For now, the world of work still expects men and women to undertake rote tasks that do not stretch these innate capabilities as far as they could. As machines take on ever more of the predictable activities of the workday, these skills will be at a premium. Automation could make us all more human.

Box 8. When some old policy ideas are new again

Many of the potential policy measures that could be adopted to help the labor force adjust to the impact of automation are not entirely new. The 1966 US Commission on Technology, Automation, and Economic Progress recommended taking actions that included improving education and training, facilitating better matching between workers and work (including greater transparency for workers), creating portable benefits that follow workers across different jobs, and increasing work-hour flexibility. These are all ideas that find echoes in today's discussions around the world.[1]

Another idea that has returned is providing a universal basic income, in other words, providing all citizens with an unconditional sum of money. Automation has given it a new lease of life among policy makers, some academics and a number of business leaders in Silicon Valley, although it remains controversial.[2] In a June 2016 referendum, Swiss voters overwhelmingly rejected a proposal to establish a universal basic income.[3]

A full basic income program has never been enacted and properly studied. However, in Finland, an experiment that started on January 1, 2017, will pay an unconditional basic income of 560 euros per month for two years to a random sample of 2,000 individuals drawn from current working-age beneficiaries of unemployment benefits. The experiment is aimed at comparing the employment rate of beneficiaries of the basic income with those who receive traditional unemployment benefits.[4]

Others have suggested that if we need human labor working alongside automation to achieve economic growth, social assistance programs should incentivize work, such as negative income taxes. The history of a negative income tax for low-paid workers spans back to the 1940s, when it was proposed by British politician Juliet Rhys-Williams, and it was advocated by Milton Friedman in the 1960s. In 1975, the United States introduced a negative income tax, the earned income tax credit, which provides income subsidies to the working poor. The program has survived for 40 years and today annual payments range from $500 for an individual with no children earning less than $14,820, to $6,242 for a family with three or more children and household income of less than $53,267.[5] Other countries have similar programs.

1 See, *A labor market that works: Connecting talent with opportunity in the digital* age, McKinsey Global Institute, October 2016; Independent work: Choice, necessity and the gig economy, McKinsey Global Institute, October 2016; and *The world at work: Jobs, pay and skills for 3.5 billion people*, McKinsey Global Institute, October June 2012.

2 See for example, Charles Murray, "A guaranteed income for every American," *Wall Street Journal*, June 3, 2016. Among business leaders, Elon Musk has spoken out in favor of such a program.

3 "Swiss voters reject proposal to give basic income to every adult and child," *Guardian*, June 5, 2016.

4 *Preparations for the basic income experiment continue*, Kela, December 14, 2016. In the 1970s, Canada launched a five-year experiment in guaranteed basic income, known as "Mincome," in Dauphin, Manitoba. The poverty level decreased, hospitalization rates fell, and high school completion rates rose. The drawback was that non-primary income earners (often mothers of small children) dropped out of the labor force. See Evelyn L. Forget, *The town with no poverty: A history of the North American guaranteed annual income social experiments*, University of Manitoba, May 2008.

5 US Internal Revenue Service.

Considerable uncertainties surround the advent of the automation era—and have done so for years. A half century ago, a US commission on technology, automation, and economic progress wrestled with some of the same questions about the future of work and employment that we do in this report.[118] The speed with which automation will be adopted into the workplace will vary, and the effects on employment, on national economies, and on businesses and workers globally will play out in myriad ways. At its core, however, automation represents a considerable opportunity for the global economy at a time of weak productivity and a declining share of the working-age population. For corporate leaders, too, automation will reshape the business landscape and create considerable future value. How to capture the opportunities and prepare for the possible consequences will be a key political, economic, corporate, and social question going forward. This is not something that can be watched from the sidelines. Automation is already here, and the technological advances continue. It is never too early to prepare.

[118] *Technology and the American economy: Report of the National Commission on Technology, Automation, and Economic Progress*, US Department of Health, Education, and Welfare, 1966.

In 2016 a computer beat the human world champion at the game of Go.
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TECHNICAL APPENDIX

This appendix outlines key points on the methodology in the following sections:

1. Assessment of technical potential for automation
2. Modeling of automation adoption timelines
3. Economic modeling
4. Key proxies and data sources

1. ASSESSMENT OF TECHNICAL POTENTIAL FOR AUTOMATION

We assess the technical potential for automation of the global economy through an analysis of the component activities of each occupation. Our analysis covers 46 countries representing more than 80 percent of the global economy. We used databases published by institutions including the World Bank and US Bureau of Labor Statistics 2014 O*Net database to break down about 800 occupations into more than 2,000 activities, and we determined the performance capabilities needed for each activity based on the way humans currently perform them.

We further break down activity into 18 capabilities and assess the technical potential of those capabilities. This framework is informed by academic research, internal expertise, and industry experts. For each capability, we define four possible levels of requirement, ranking from not required to the equivalent to top-quartile human performance. Exhibits A1 to A4 give a high-level summary of the capabilities and the four continuum criteria.

Exhibit A1

Criteria for automation: Accept input

	Score (based on tech advancements and complexity)				
		Requirement: Basic to execute task		Requirement: High human (top quartile of global labor pool)	
Automation capability	**0**	**1**	**2**	**3**	**Metric to define continuum**
Natural language understanding	Does not require NLU	Low language comprehension required (while still accurate with structured commands)	Moderate language comprehension (medium accuracy of nuanced conversation)	High language comprehension and accuracy, including nuanced human interaction and some quasi language	▪ Accuracy of comprehension ▪ Complexity of language/ context/ integration
Sensory perception	Does not require sensory perception	Autonomously infers simple external perception (e.g., object detection, light status, temperature) using sensory data	Autonomously infers more complex external perception using sensors (e.g., high resolution detail, videos) and simple integration using inference	High human-like perception (including ability to infer and integrate holistic external perception)	▪ Accuracy of perception/ complexity of scene ▪ Degree of integration across sensors
Social and emotional sensing	Does not require social and emotional sensing	Basic social and emotional sensing (e.g., PAD emotion model in mechanical systems)	Comprehensive social and emotional sensing (e.g., voice, facial and gesture recognition-based social and emotional sensing)	High human like social and emotional sensing	▪ Quality of comprehension

SOURCE: McKinsey Global Institute analysis

Exhibit A2

Criteria for automation: Information processing

	Score (based on tech advancements and complexity)				
		Requirement: Basic to execute task		Requirement: High human (top quartile of global labor pool)	
Automation capability	**0**	**1**	**2**	**3**	**Metric to define continuum**
Recognizing known patterns/ category (supervised learning)	Does not require pattern/category recognition	Recognition of basic known patterns/categories (e.g., lookup functions in data modeling)	Recognition of more complex known patterns/ categories	High human-like recognition of known patterns	▪ Complexity of pattern
Generation of novel patterns/ categories	Does not require pattern/category generation	Simple/basic ability for pattern/category generation	More advanced capacity for recognition of new patterns/categories and unsupervised learning	High human-like recognition of new patterns/ categories, including development of novel hypotheses	▪ Complexity of pattern
Logical reasoning/ problem solving	Does not require contextual knowledge or interpretation of novel inputs	Capable of problem solving based on contextual information in limited knowledge domains with simple combinations of inputs	Capable of problem solving in many contextual domains with moderately complex inputs	Capable of extensive contextual reasoning and handling multiple complex, possibly conflicting, inputs	▪ Complexity of context and inputs
Optimization and planning	Does not require optimization and planning	Simple optimization (e.g., optimization of linear constraints)	More complex optimization (e.g., product mix to maximize profitability, with constraint on demand and supply)	High human-like optimization and planning based on judgment (e.g., staffing a working team based on team/individual goals)	▪ Degree of optimization (single vs. multi variate)
Creativity	Does not require creativity	Some similarity to existing ideas/concepts	Low similarity to existing ideas/concepts	No similarity to existing ideas/concepts	▪ Novelty/ originality and diversity of ideas
Information retrieval	Does not require information retrieval	Search across limited set of sources (e.g., ordering parts)	Search across multiple set of diverse sources (e.g., advising students)	Expansive search across comprehensive sources (e.g., writing research reports)	▪ Scale (breadth, depth, and degree of integration) of sources ▪ Speed of retrieval
Coordination with multiple agents	Does not require collaboration	Limited group collaboration; low level of interaction	Regular group interaction requiring real-time collaboration	Complex group interaction requiring high human like collaboration	▪ Complexity of coordination (i.e., number of interactions per decision) ▪ Speed/frequency of coordination
Social and emotional reasoning	Does not require social/emotional reasoning	Basic social and emotional reasoning	More advanced social and emotional reasoning	High human-like social and emotional reasoning	▪ Complexity of emotional inference

SOURCE: McKinsey Global Institute analysis

Exhibit A3

Criteria for automation: Deliver output

	Score (based on tech advancements and complexity)				
		Requirement: Basic to execute task		Requirement: High human (top quartile of global labor pool)	
Automation capability	**0**	**1**	**2**	**3**	**Metric to define continuum**
Output articulation/ display	Does not require any articulation/ display	Articulation of simple content (e.g., organizing existing content)	Articulation of moderately complex content	High human-like articulation	▪ Complexity of message delivered ▪ Variability in medium of message delivered
Natural language generation	Does not require NLG	System output with basic written NLG (e.g., web crawl results)	System output with advanced NLP (more complex structure)	Nuanced, high human-like language output	▪ Complexity of message delivered. Note: includes use of quasi linguistics (idioms, common names, etc.) ▪ Accuracy of audience interpretation
Emotional and social output	Does not require social and emotional output	Simple social and emotional discussions (e.g., conversations with no gestures)	Advanced social and emotional discussions (e.g., conversations with gestures)	Nuanced high human-like body language and emotional display	▪ Complexity of emotional communication ▪ Accuracy of audience interpretation

SOURCE: McKinsey Global Institute analysis

Exhibit A4

Criteria for automation: Physical movement

	Score (based on tech advancements and complexity)				
		Requirement: Basic to execute task		Requirement: High human (top quartile of global labor pool)	
Automation capability	**0**	**1**	**2**	**3**	**Metric to define continuum**
Fine motor skills/dexterity	Does not require physical dexterity	Ability to handle and manipulate common simple objects (e.g., large solid objects) using sensory data	Can handle and manipulate wide range of more complex and delicate objects (e.g., pick up egg)	High human dexterity and coordination	▪ Precision, sensitivity, and dexterity of manipulation
Gross motor skills	Does not require gross motor skills	Basic 1D/2D motor skills	More advanced multi-dimensional motor skills	High human multi-dimensional motor skills	▪ Range and degree of motion ▪ Speed and strength of motion
Navigation	Does not require localization/ navigation	Use pre-defined algorithm for mapping and navigation	Autonomous mapping and navigation in simple environment	Autonomous mapping and navigation in complex environment	▪ Complexity of environment (while still maintaining accuracy)
Mobility	Does not require mobility	Mobility/locomotion in simple environment (e.g., limited obstacles/office space)	Mobility/locomotion in more complex terrain of human scale environment (e.g., climbing stairs)	High human mobility and locomotion	▪ Speed (gross motor) of mobility ▪ Scale of mobility (2D vs. 3D) ▪ Complexity of environment/ terrain

SOURCE: McKinsey Global Institute analysis

Assigning the required level of capabilities to activities

We used a machine-learning algorithm to score the more than 2,000 work activities in relation to the 18 performance capabilities. To train the algorithm we devised a list of keywords that we shared with experts. The algorithm scores each activity by matching keywords from the capability to the activity title. Where we found anomalies, special requirements, or a need for nuance, we made adjustments, for example, in assessing the level of capabilities needed to navigate in extreme weather or on uneven surfaces and other unpredictable settings, or the different physical capabilities required by a kindergarten teacher compared with a middle school teacher.

2. MODELING OF AUTOMATION ADOPTION TIMELINES

Our adoption model assesses the automation development and adoption timeline at activity level for more than 800 occupations across 19 sectors as well as 46 countries, which represent more than 80 percent of the global economy. We divide the adoption process into four phases: technical feasibility, solution development, economic feasibility, and end-user adoption.

Technical feasibility

For a work activity to be automated, every performance capability needed to carry out that activity must advance to the required technical level. To develop progression scenarios for the development capabilities, we used survey findings, extrapolation of metrics, and other predictors of technical advances. We conducted interviews with industry leaders and academic experts. We also looked at some recent commercial successes showcasing capabilities, as well as historic trajectory of capabilities. We then adjusted the result using some identified constraints that could limit the progression of certain capabilities.

To improve accuracy, we looked at other predictors, including from the press, companies, research groups, and relevant industries. These predictors include research and technological breakthroughs, trends in publications, and patents as a measure of research potential. We also looked at predictors of computational resources that are required for capabilities as compared with Moore's law. Another important predictor is open source and crowdsourcing developments that could potentially accelerate the technology growth.

Based on the assessment, we projected the reasonable expected time frames to reach the next level of performance for each capability.

Solution development

To estimate how long it would take to develop a solution that could integrate automation technologies after the establishment of technical feasibility, we used a three-step process.

First, to understand the solution development life cycle, we collected the development time and technical capabilities for more than 100 previously developed automation solutions, including both hardware and software solutions. We recorded the number of years from initial research to development (product launch) as well as up to three of the most relevant capabilities for each.

Second, we generated solution development scenarios, taking the 25th and 75th percentile development time for each of the 18 capabilities across all of its associated solutions.

Third, we estimated the solution development time for a given work activity based on the maximum solution development time of capabilities that activity required. Several examples are assessed to ensure accuracy, and we assign 25th and 75th percentile to the earliest/latest scenario correspondingly.

Economic feasibility

Once a solution is developed, we assume the activities will start to be automated after the cost of the solution falls below the level of wages for that activity. For this calculation, we took into account both the evolution of solution costs and the evolution of wages.

Solution cost evolution

Based on the capability requirements, solutions are classified into two categories, hardware and software. If a solution requires sensory perception, fine motor skills and dexterity, gross motor skills, or mobility, it is classified as a hardware solution. Otherwise, it will be classified as a software solution. For a given solution, the initial cost is estimated as a percentage of the highest hourly wage for the corresponding activity across all the countries we modeled. We estimated the initial cost by looking at several examples of solutions developed using different mixes of hardware and software. Based on our research, most of the software solutions have relatively low initial costs as a percentage of the human labor cost. Some solutions that require a combination of both software and hardware components have a higher initial cost. To be conservative, we exclude certain solutions, whose advantages are to be derived from only very specific scenarios or include non-economic benefits such as increased quality and efficiency as well as decreased error rates. The range of initial solution cost we model for hardware is 20 to 70 percent of the highest hourly wage for the corresponding activity in the world, and 0 to 20 percent for software.

In our model, the solution costs decrease as technology advances, with hardware solution costs declining by 16 percent per year and software solution costs declining by 5.3 percent per year. We triangulate consumer price index and supplier surveys to estimate the hardware solution cost reduction. For this, we use computer software and accessories indexes to estimate software solution cost reduction, and, for, consumer price inflation, we used consumer price index data for personal computers and peripheral equipment, and for computer software and accessories from the US Bureau of Labor Statistics. For software solution costs we used a survey of prices from the International Federation of Robotics. Further work could be done to refine the estimation; however, given software's low starting cost, annual reduction has little impact on final automation results.

Wage evolution

We model the wage evolution for each country in two stages. From today until 2030, we apply country-level growth estimates for all countries. The McKinsey Global Growth Model provides wage data to 2030 for G20 countries and other major regions. We use best proxy to estimate the remaining 26 countries not covered by the McKinsey model. As the data are in local currency, we convert it into 2010 constant US dollars, by dividing nominal GDP by corresponding country-level consumer prices (2010 base) and times the exchange rate to the dollar (2010 base). We then calculated a compound annual growth rate (CAGR) for each country. For 2030 onward, we group the 46 countries for which we have data into two cohorts using a cutoff country-level annual wage, based on the wage distribution from 2016 to 2030. Countries within the same cohort grow at same rate. The cohort-level wage growth rate is then estimated using the CAGR from 2016 to 2030 of the corresponding G20 country within the cohort. The cutoff level also evolves at 2.66 percent annually, which is the median G20 CAGR between 2016 and 2030. We reclassify countries each year. As a country advances into the next cohort, the appropriate growth rate will be applied. The detailed proxy assignment and grouping is listed in Exhibit A5.

Exhibit A5

We approximate 26 countries with proper proxy till 2030 and classify them into two cohorts with group-level growth rate for 2030 onward

McKinsey Global Growth Model (GGM) prediction and proxy

GGM provides country-level growth rate for G19 + Spain

We use GGM's regional data to approximate the other 26

Other Western Europe
- Austria
- Czech Republic
- Netherlands
- Norway
- Sweden
- Switzerland

Other sub-Saharan Africa
- Kenya
- Nigeria

Saudi Arabia
- Bahrain
- Kuwait
- Qatar
- United Arab Emirates

Other Middle East and North Africa
- Egypt
- Morocco
- Oman

Other developed East Asia and Pacific
- Singapore

Other South Asia
- Malaysia
- Philippines
- Thailand

Other Latin America and Caribbean
- Barbados
- Chile
- Colombia
- Costa Rica
- Peru

Other Eastern Europe and Central Asia
- Poland

Other PIIGS
- Greece

Cohort growth

24 high-income countries[1] with 1.95% growth rate[2]
- Australia
- Austria
- Bahrain
- Canada
- France
- Germany
- Greece
- Italy
- Japan
- Kuwait
- Netherlands
- Norway
- Qatar
- Saudi Arabia
- Singapore
- South Korea
- Spain
- Sweden
- Switzerland
- United Arab Emirates
- United Kingdom
- United States

22 low-income countries[1] with 3.12% growth rate[2]
- Argentina
- Barbados
- Brazil
- Chile
- China
- Colombia
- Costa Rica
- Czech Republic
- Egypt
- India
- Indonesia
- Kenya
- Malaysia
- Mexico
- Morocco
- Nigeria
- Oman
- Peru
- Philippines
- Poland
- Russia
- South Africa
- Thailand
- Turkey

Starting 2017, countries are regrouped each year based on the evolving cut-off derived from averaged country-level wage distribution

1 Adjusted UN standard based on wage distribution.
2 Growth rate is the median G19 compounded annual growth rate over 2016–30 for corresponding cohorts.

SOURCE: McKinsey Global Institute analysis

Adoption and deployment

Adoption can start once solutions are economically feasible, but several factors can still hinder or enable both the timing and the pace of adoption. Solutions requiring different technologies have different levels of ease. It takes time to integrate capabilities needed into current technical platforms and combine them as an organic entity. Barriers also exist from the organization side. Human talent and organization structures might act as bottlenecks to implementation. Policies and law could also slow down or speed up technology innovation and adoption. Finally, consumers might have varied preferences for automated solutions due to perceived fears and emotional reactions, which could affect the adoption timing.

To incorporate all these factors, we use the mathematics of the Bass diffusion model, a well-known and widely used function in forecasting, especially for new products' sales forecasting and technology forecasting.

$$\frac{f(t)}{1-F(t)} = \left(p + qF(t)\right)$$

Where $F(t)$ is the installed base fraction (that is, adoption of given technology or product) and $f(t)$ is the corresponding rate of change.

The function in our case also contains two key parameters: p parameter (inherent tendency of consumers to adopt new technology), and q parameter (the tendency of consumers to adopt based on peer adoption). Parameters are estimated through ordinary least square regression. In the absence of data, p and q parameter values from meta-analyses can be used if saturation value is known or can be guessed.

We then simulate two scenarios for known historic technology adoption curves (see Exhibit 21 in the main report). The technologies we used are stents, airbags, laparoscopic surgery, MRI, smartphones, TVs, antilock braking systems, online air booking, cellphones, color TVs, SxEW leaching (copper), personal computers, electronic stability control, instrument landing systems, dishwashers, and pacemakers. The fitted values of parameters p and q are consistent with other academic research.[119] It takes about five years to reach 50 percent adoption in the earliest scenario and approximately 16 years in the latest scenario.

3. ECONOMIC MODELING

To better understand the economic implication of automation, we examine it at both the global and country levels. Key assumptions are similar across the two levels. The global level is essentially an aggregated version of major countries including the G19 and Nigeria.

Our analysis is based on three primary components at country level: projected number of full-time equivalents (FTE), the number of full-time employees needed to maintain GDP per capita and achieve GDP per capita projection, and automation output.

Projected number of full-time employees

The projected FTE data indicates the labor force evolution. For a given year in a given country, it is calculated as:

$$Projected\ FTE = Population \times Labor\ participation\ rate \times Projected\ unemployment\ rate$$

[119] Based on an empirical generalization from 218 technologies. See Fareena Sultan, John U. Farley, and Donald R. Lehmann, "Reflections on 'A meta-analysis of applications of diffusion models,'" *Journal of Marketing Research*, volume 33, number 2, May 1996; time periods are annual.

We modeled different segments: ages 0–14, ages 15–24, ages 24–64 female, ages 24–64 male, and ages 65-plus. For each segment we gathered data on:

- Population: Our model uses the United Nations projection on population to 2065.
- Labor participation rate: We use historical data from the International Labour Organisation to 2012. We estimate future participation conservatively, taking the highest rate between 2007 and 2012 and fixing it for the future for each segment. For the participation rate of the 0–14 age segment, we assume it will remain the same as in 2012.
- Unemployment rate: We again use data from the ILO and assume it will be at the long-term steady state average moving forward.

GDP per capita projection

From today to 2030, we use the GDP projection from the McKinsey Global Growth Model. From 2030 to 2065, we made GDP projection with a cohort growth model. Based on the distribution of GDP per capita as of today, we grouped countries into two cohorts and calculated the cohort-level growth rate. Countries within same cohort grow at the same rate. The cutoff of groupings also evolve every year at 1.58 percent, which is the average CAGR of all countries from 2016 to 2030.

The two cohorts are as follows:

- Nine high-income countries, with a 1.08 percent growth rate from 2030 onwards: Australia, Canada, France, Germany, Italy, Japan, South Korea, United Kingdom, and United States.
- Eleven middle-income countries, with a 2.04 percent growth rate from 2030: Argentina, Brazil, China, India, Indonesia, Mexico, Nigeria, Russia, Saudi Arabia, South Africa, and Turkey.

Number of FTEs needed to maintain GDP per capita or its projection

Assuming zero productivity growth, we calculate the required level of FTE to maintain both the GDP per capita as of today and the projected GDP per capita. As to maintain current GDP per capita, number of FTE needed is calculated by using current GDP per capita times total population and divided by current productivity as of 2014. The number of FTE required to maintain projected GDP per capita is calculated in a similar way. With projected GDP per capita mentioned above, the result is then multiplied by total population and divided by productivity as of 2014 to get the number of FTE needed.

Automation output

Using the projected FTE and estimated automation adoption, we calculate automation output under different scenarios by multiplying them together. This enables us to gauge automation impact in terms of human labor. To maintain consistency with other data sources we leveraged, we made several additional assumptions. We consider only those job activities that are available and well defined today. Also, we assume automation has a labor substitution effect but no other performance gains, to be conservative. Finally, we assume labor replaced by automation will rejoin the workforce at the same of productivity as today. We also assume that additional output from automation will not decrease even if the total number of FTEs declines as a result of demographic changes.

Basic assumptions and calculations remain the same at the global level. The only difference is that we average key indicators such as global growth based on averaged GDP, population, and participation rate as well as unemployment rate across G19 plus Nigeria. We make an adjusted calculation for the number of FTE at a global level. Given the nature of FTE, it must be aggregated with adjustments based on corresponding country-level productivity. We essentially recalculate the global level average productivity using country-level data as follows:

$$\frac{\sum_{G19+Nigeria} productivity \times number\ of\ FTE}{\sum_{G19+Nigeria} number\ of\ FTE}$$

The global level averaged productivity is then divided by global-level GDP to calculate corresponding number of FTE. Without this adjustment, the number of FTE needed to maintain GDP growth will be inflated given difference on productivity across countries.

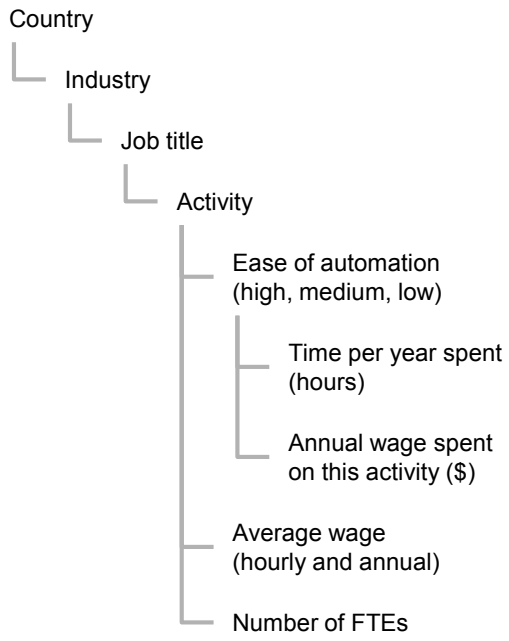
4. KEY PROXIES AND DATA SOURCES

All of the findings about automation derived from our model are backed up by the database we built, which captures detailed information from country, sector, job, and specific activity level, corresponding time spent, and wages for certain activities. At each industry, job, and activity level, we also calculated the corresponding impact using wage and number of full-time employees. Exhibit A6 shows the database structure and key calculations. We leverage many data sources, both internal and external, however, some approximation was needed since the data are not comprehensive.

Exhibit A6

Our approach to model design and estimating impact of automation

Database structure



Impact definition

Impact by job title ($ per year)	=	Number of FTEs	x	Annual wage ($)		
Impact by activity ($ per year)	=	Number of FTEs[1]	x	Time spent on activity per year (hours)	x	Average hourly wage ($)
Impact by industry	=	$\sum_{\text{Job title}}$ (Number of FTEs	x	Annual wage ($))		

1 FTE whose job titles include these detailed work activities.

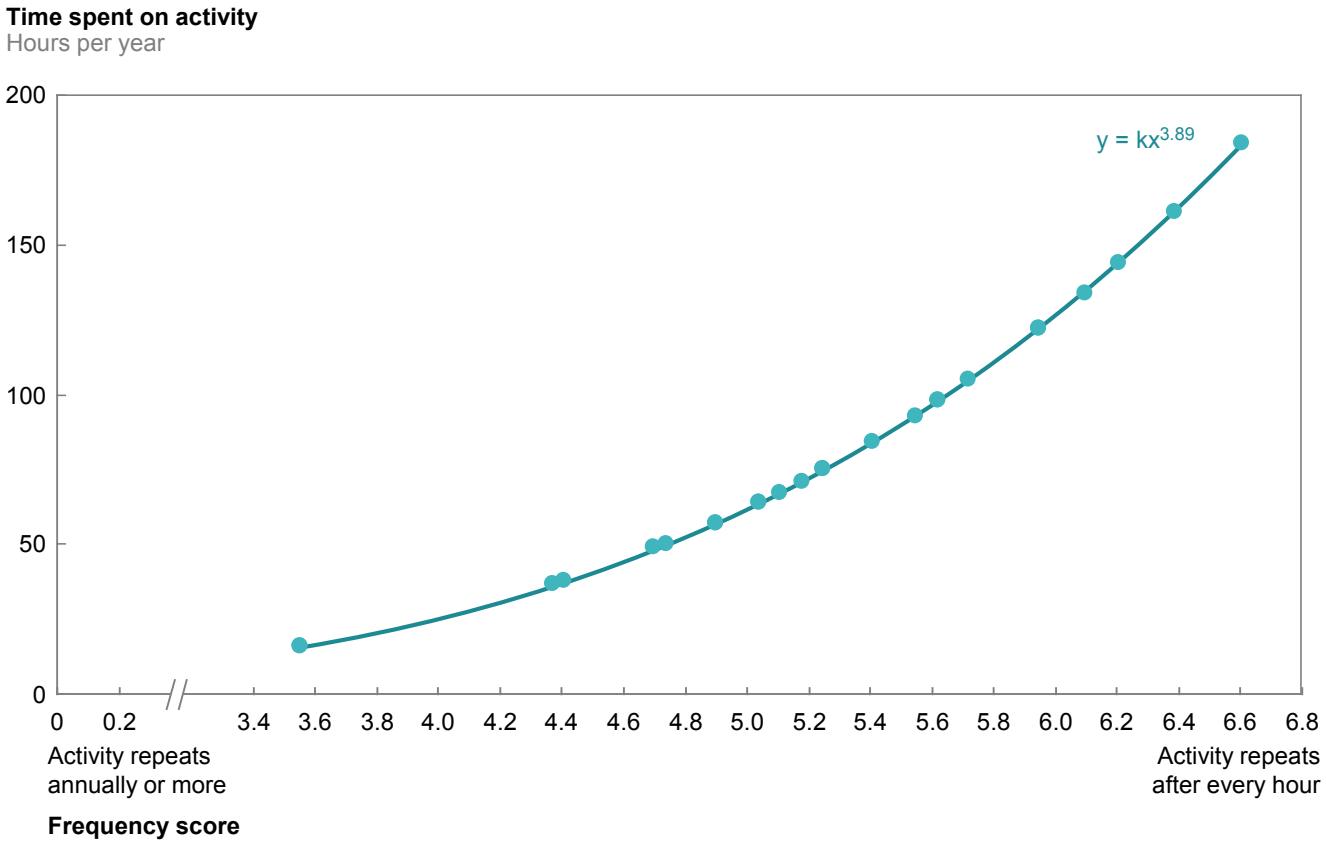
SOURCE: McKinsey Global Institute analysis

To gain insights on the impacts of automation, it is important to look at occupations as well as activity levels. However, time spent on each activity by occupation is not directly available. The US Bureau of Labor Statistics 2014 O*Net database provides frequency scores for each activity ranging from 1 (with a significant range of year level) to 7 (with a significant range of hour level). The score is used to calculate corresponding time factors. We plot these scores against the time factor, which is assigned for given integer frequency. Assuming there are 2,080 working hours per year, we scale to calculate time spent on each activity by job title. Exhibit A7 illustrates our methodology using a cashier as an example.

Exhibit A7

We converted frequency to number of hours using best fitting curve and validated it with job description based on our case studies

Cashier example

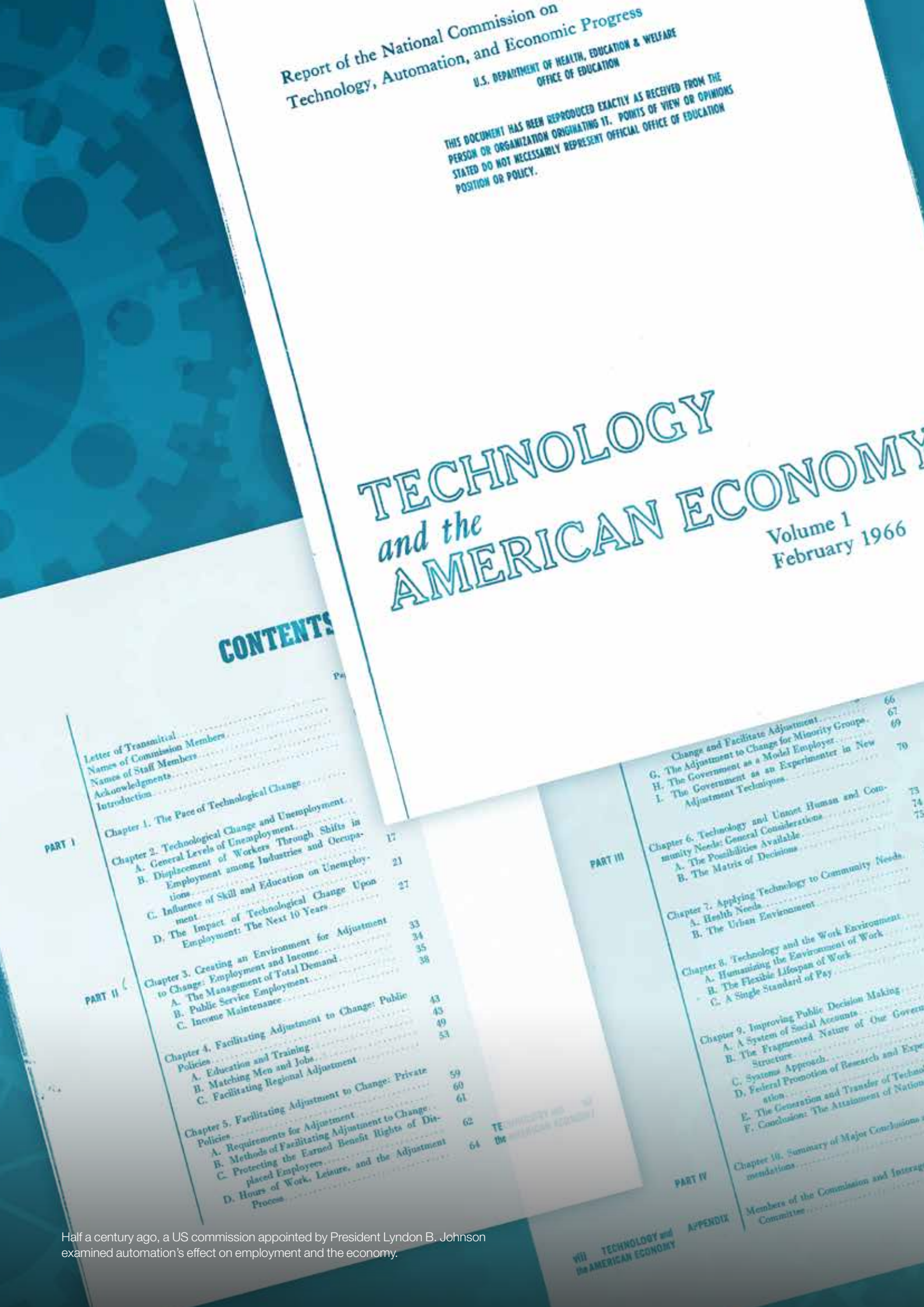


SOURCE: US Bureau of Labor Statistics; McKinsey Global Institute analysis

Data mapping and approximations

To compensate for a lack of consistent categorizations and level granularity of labor data across all countries, we made estimates by mapping, proxies, and approximations. For major countries, we extracted high-level employment data for nine major occupations across 19 sectors from Oxford Economic Forecasts. India's data were used to estimate the agriculture sector for Brazil. We then combined these data with our own international employment database, which contains detailed occupation data for Australia, Brazil, Canada, France, the United Kingdom, and the United States. For all other countries where data were missing, we defined and assigned proxies to them, based on GDP per capita and output per capita, sector mix, and education levels. The key proxy defining process contains two parts, the proxy for 39 major countries and the proxy for selected African countries.

For the 39 major countries, we leveraged existing external and internal McKinsey & Company resources and assigned different proxies to countries within each industry. Taking agriculture, which has 28 percent of the global employees, as an example, we use India to approximate China and Indonesia, given the similarity in farm size and GDP per capita. For smaller industries, we use a weighted combination between Brazil and the developed countries for which we have detailed data.



Half a century ago, a US commission appointed by President Lyndon B. Johnson examined automation's effect on employment and the economy.

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