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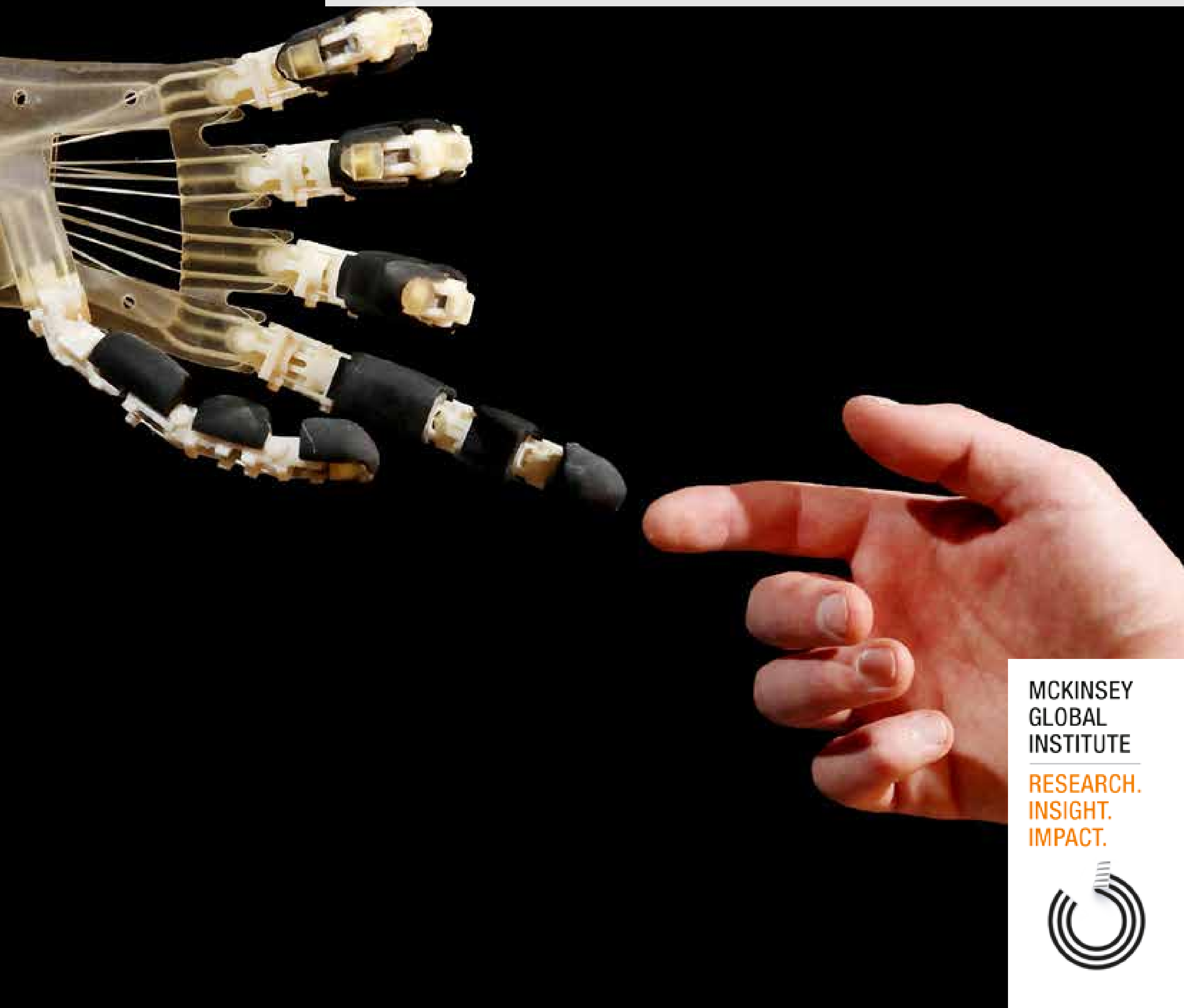
A FUTURE THAT WORKS: AUTOMATION, EMPLOYMENT, AND PRODUCTIVITY

JANUARY 2017

EXECUTIVE SUMMARY



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A FUTURE THAT WORKS: AUTOMATION, EMPLOYMENT, AND PRODUCTIVITY

JANUARY 2017

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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.
- Almost half the activities people are paid almost $16 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

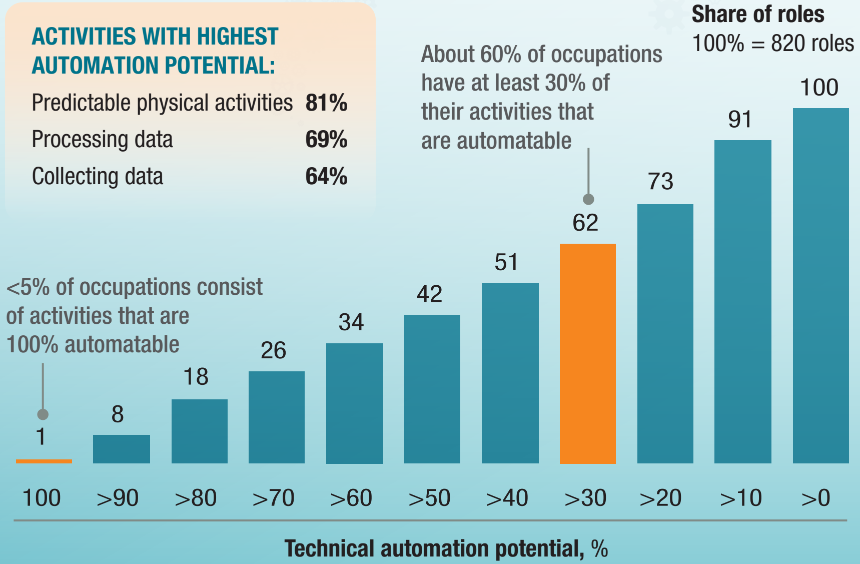
A global force that will transform economies and the workforce

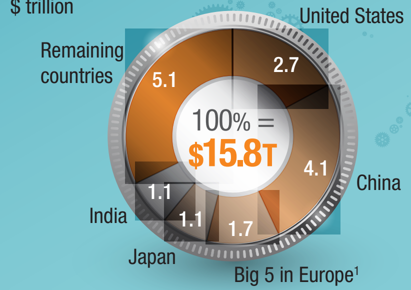
Technical automation potential by adapting currently demonstrated technologies

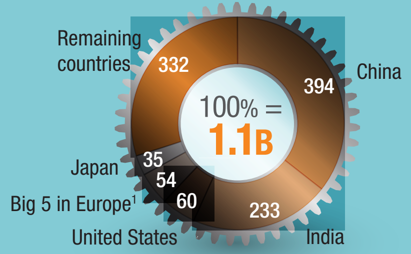
While few occupations are fully automatable, 60 percent of all occupations have at least 30 percent technically automatable activities

ACTIVITIES WITH HIGHEST AUTOMATION POTENTIAL:

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





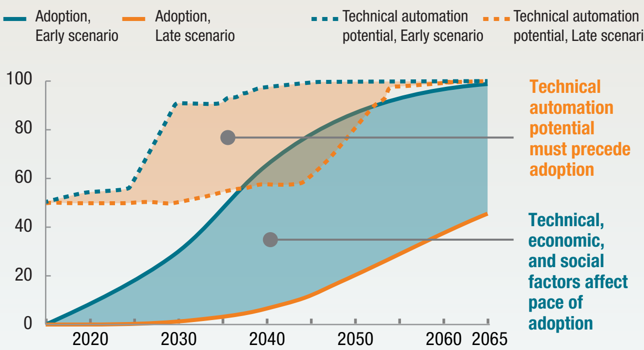


[1] France, Germany, Italy, Spain, and the United Kingdom.

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, %

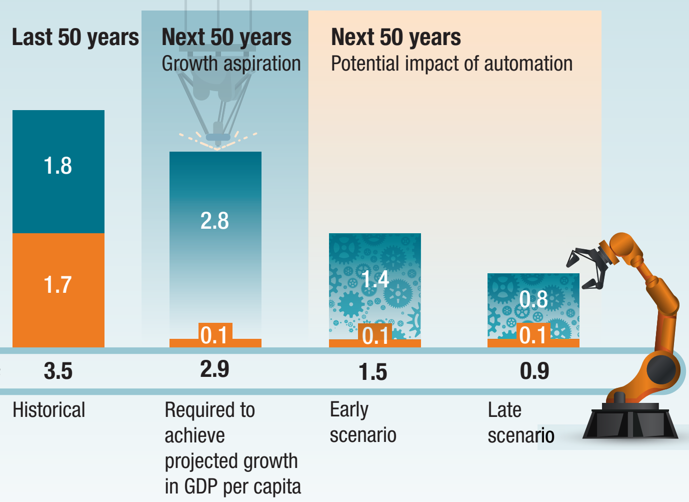


Automation will boost global productivity and raise GDP

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.

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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.

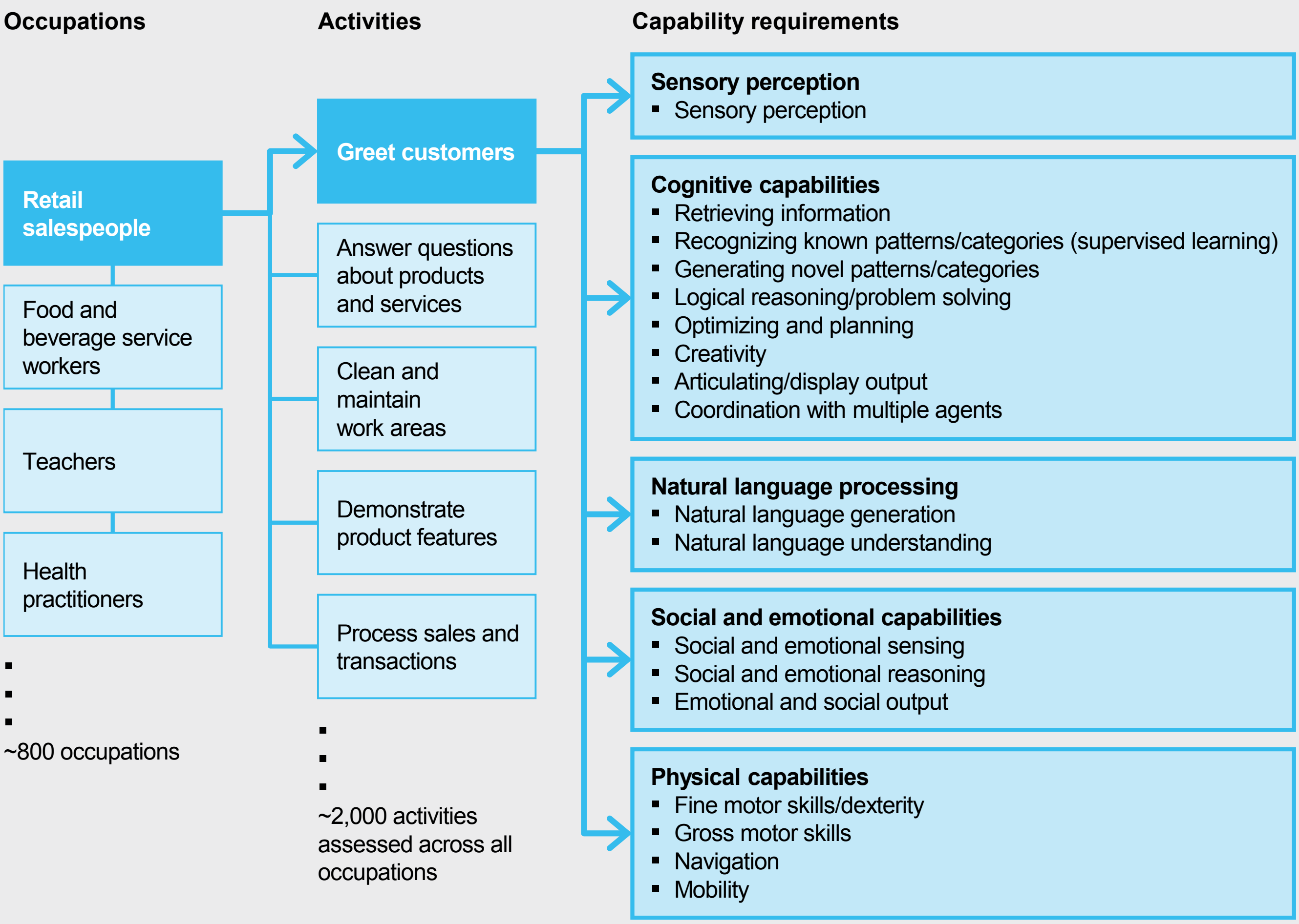
We estimated the level of performance for each of these capabilities that is required to perform each work activity successfully, based on the way humans currently perform activities—that is, whether the capability is required at all, and if so, whether the required level of performance was at roughly 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

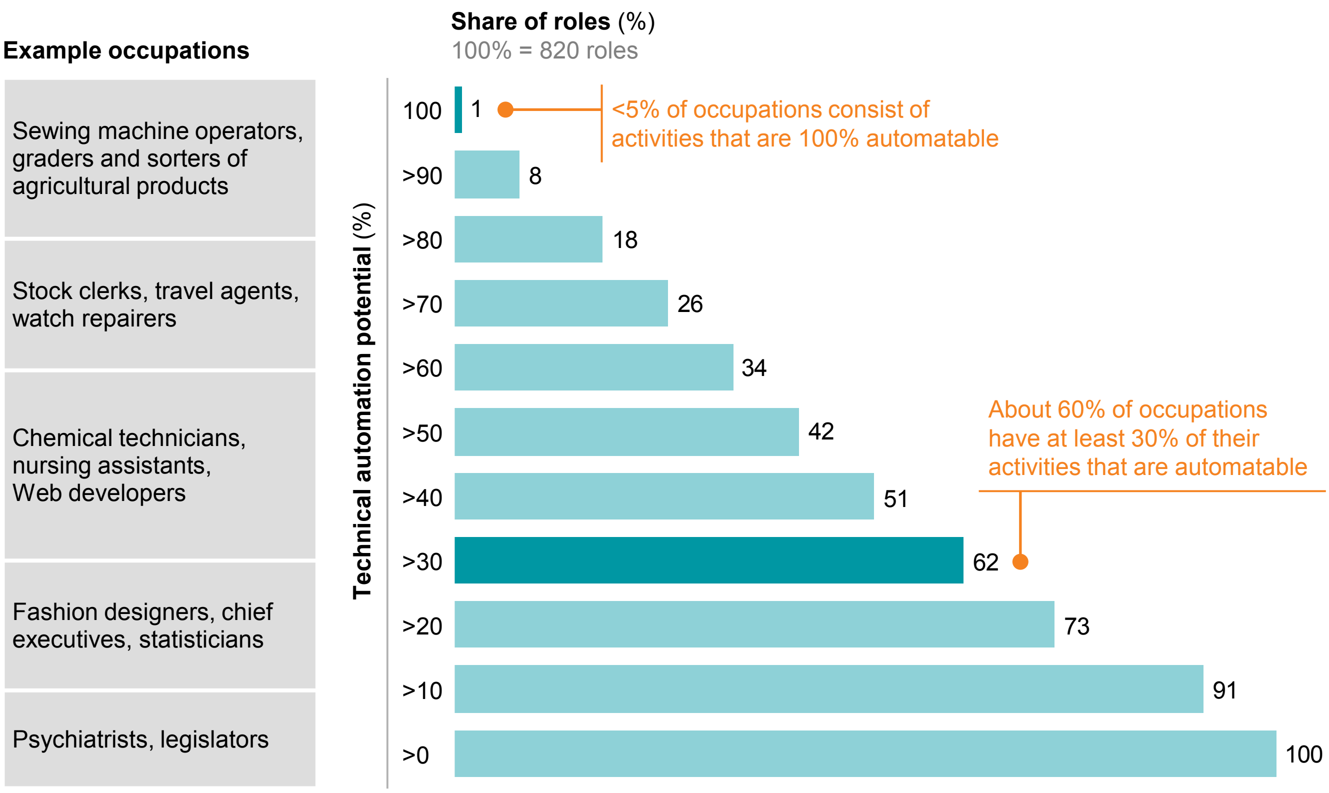
Unlike some other studies, the core of our analysis focuses on work activities rather than whole occupations. We consider work activities a more relevant and useful measure since occupations are made up of a range of activities with different potential for automation.[8] For example, a retail salesperson 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 49 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]



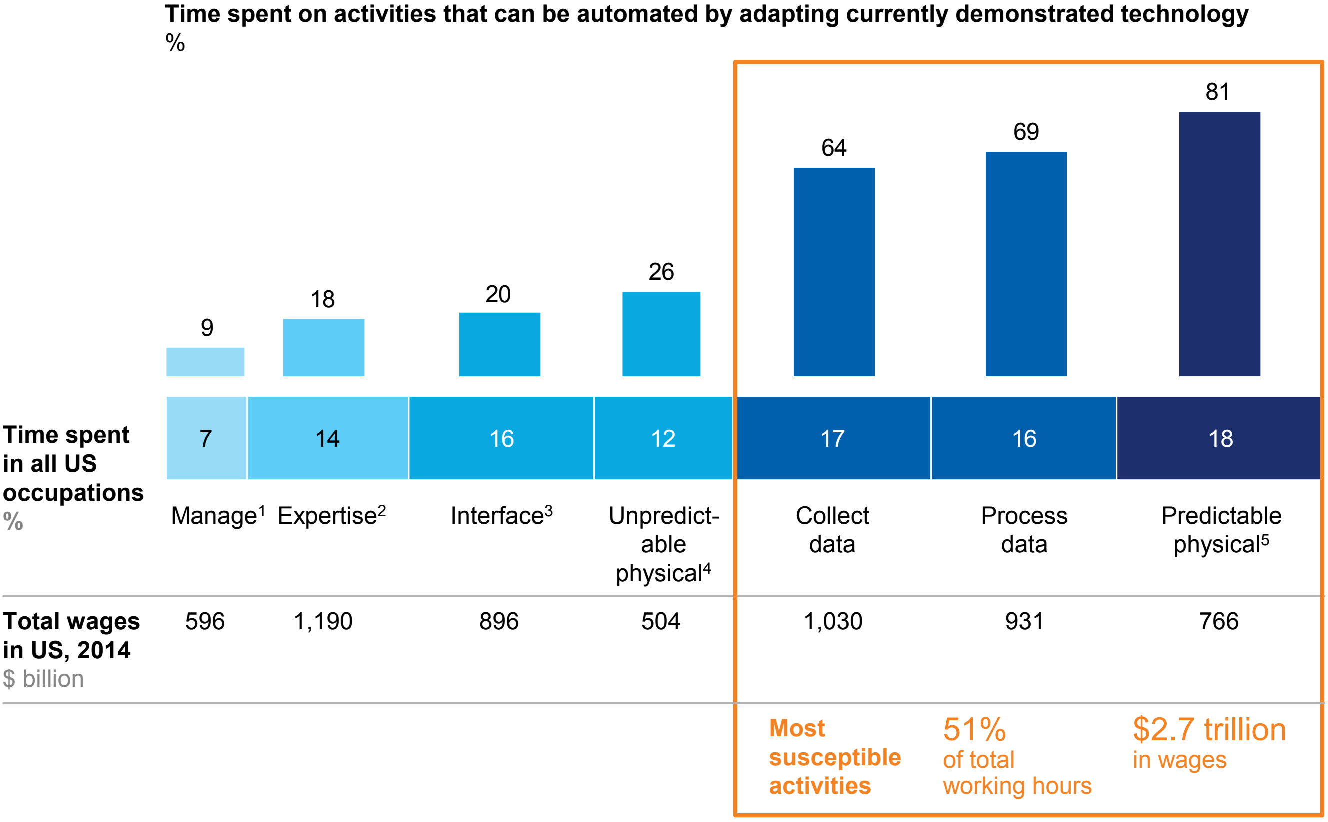
1 We define automation potential according to the work activities that can be automated by adapting currently demonstrated technology.

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



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

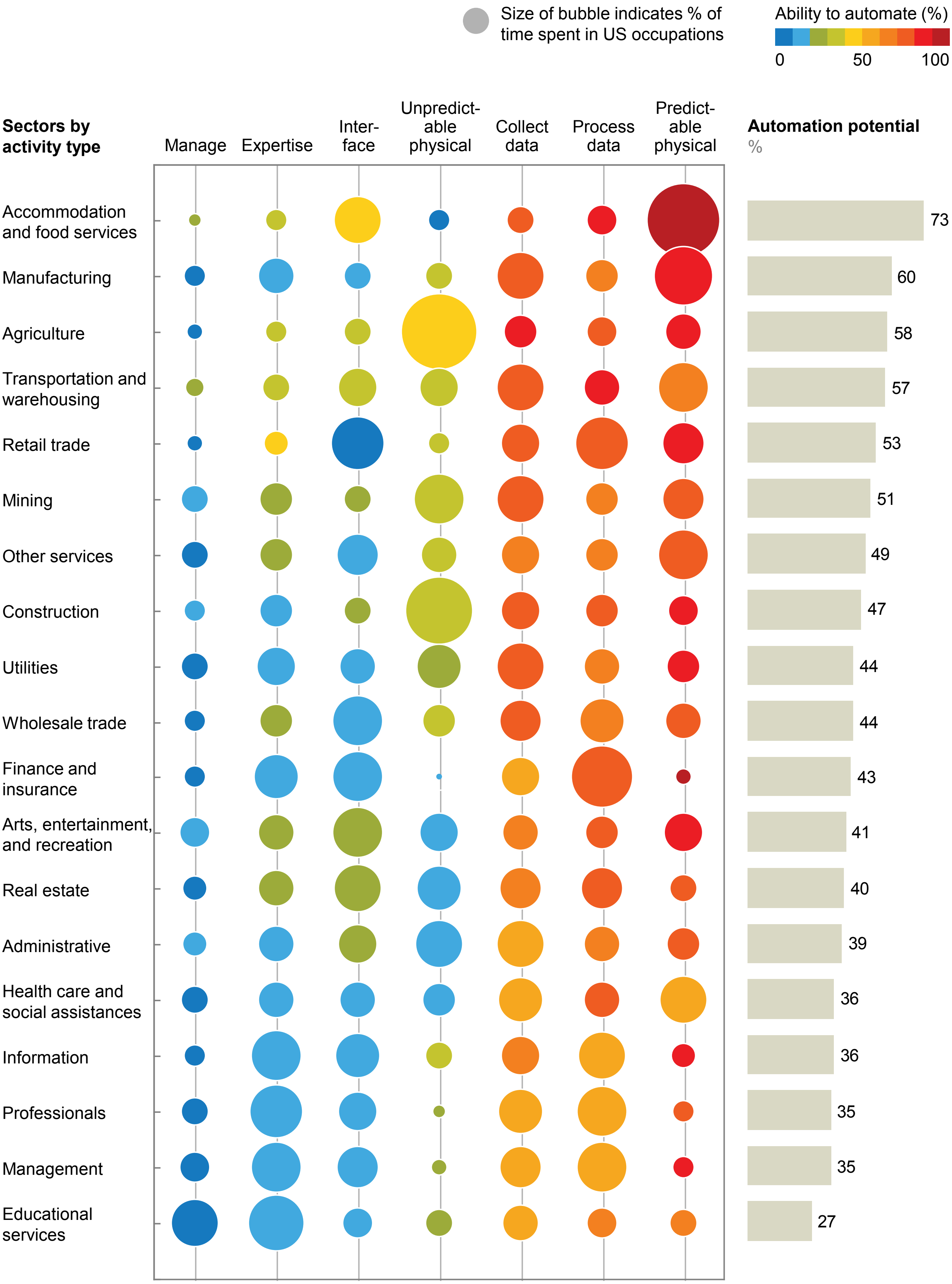
The degree of automation potential varies considerably among sectors and countries

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 1.1 billion employees and $15.8 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, 54 million full-time employee equivalents and more than $1.7 trillion in wages are associated with technically automatable activities in the five largest economies—France, Germany, Italy, Spain, and the United Kingdom.

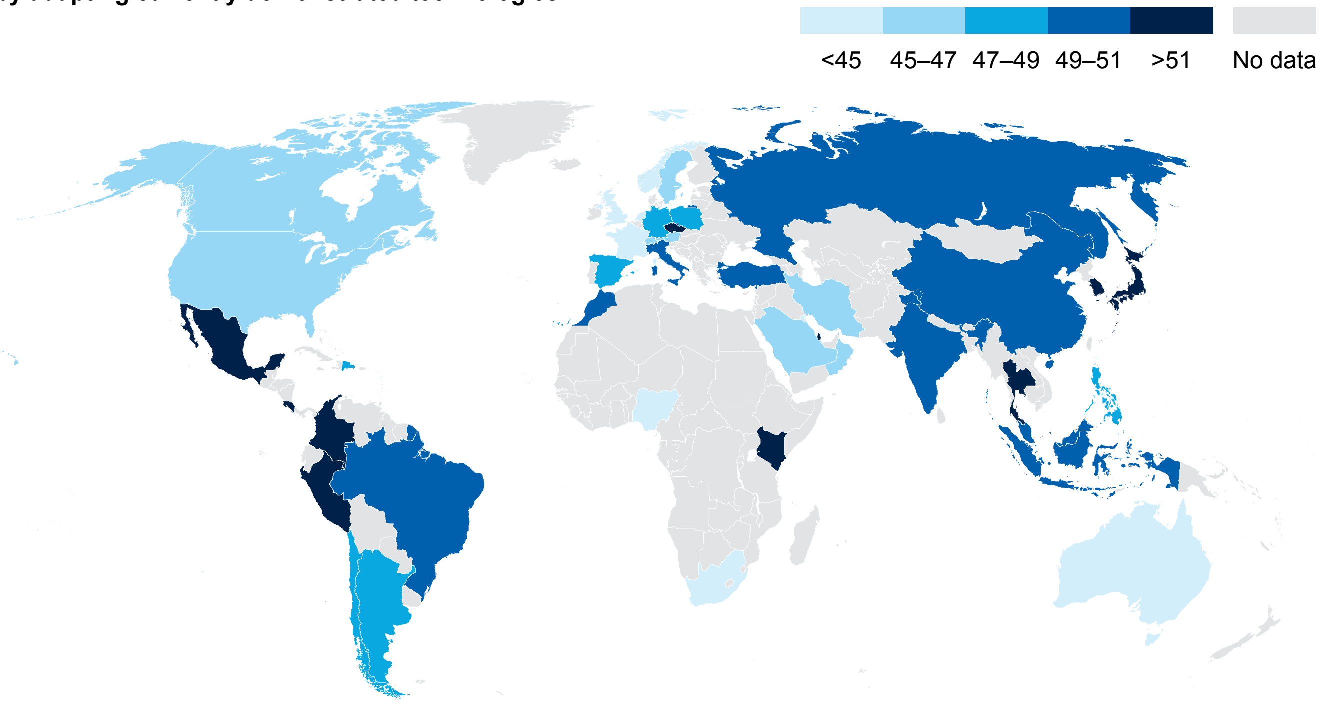
Our analysis of the technical automation potential of the global economy shows that there is a range among countries of about 15 percentage points. Two factors explain this range. The first is the sectoral makeup of each economy, that is, the proportion of a national economy that is in sectors such as 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]

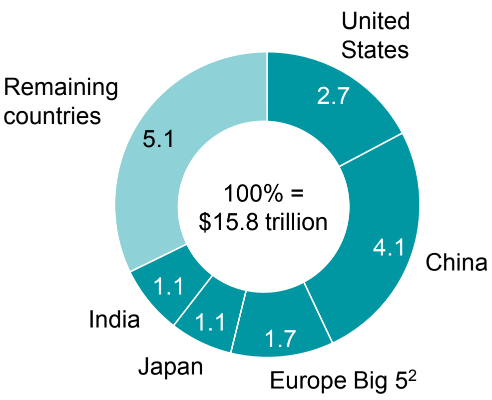


Technical automation potential is concentrated in countries with the largest populations and/or high wages

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

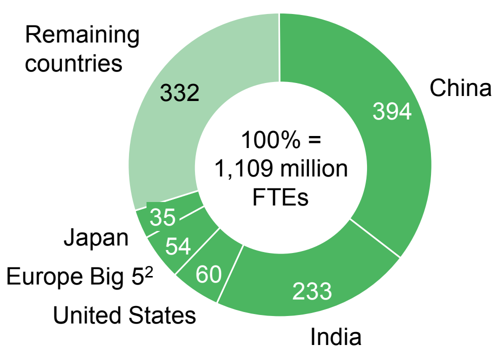
Wages associated with technically automatable activities

$ trillion



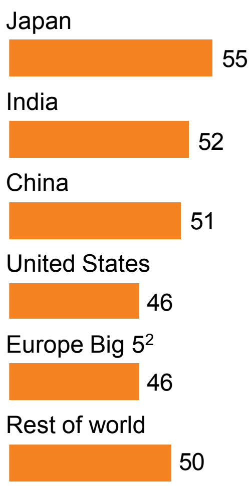
Labor associated with technically automatable activities

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.

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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.

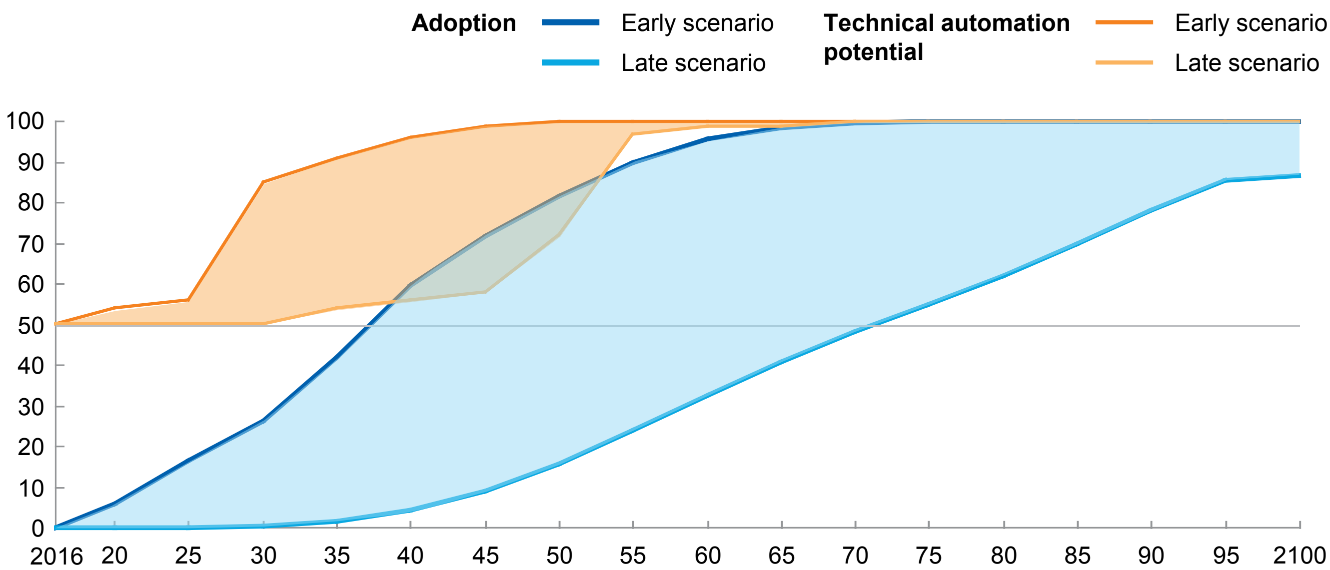
This magnitude of shifts in work activities over multiple decades is not unprecedented. In the United States, for example, the share of farm employment fell from 40 percent in 1900 to 2 percent in 2000, while the share of manufacturing employment fell from approximately 25 percent in 1950 to less than 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]
%



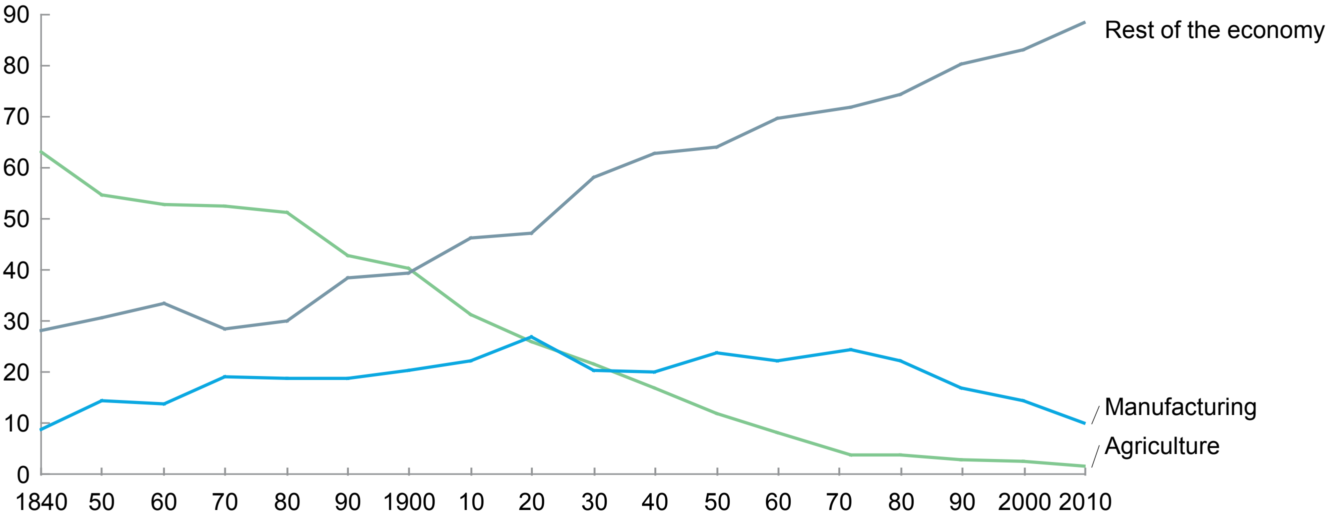
1 Forty-six countries used in this calculation, representing about 80% of global labor force.

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.

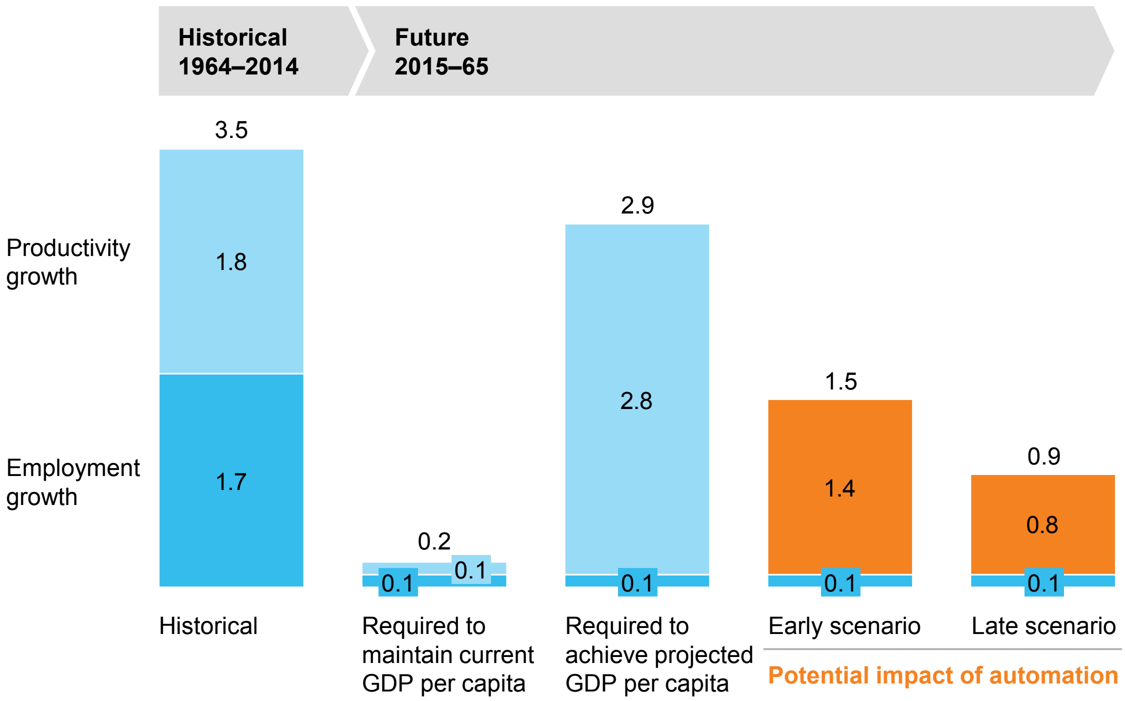
the growth of their working population.[19] For these economies, automation can provide the productivity injection needed just to maintain current GDP per capita. To achieve a faster growth trajectory that is more commensurate with their developmental aspirations, these countries would need to supplement 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.

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[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.

•••

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.

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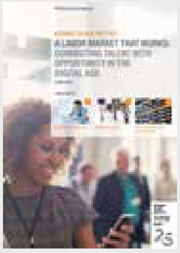

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