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Where machines could replace humans—and where they can't (yet)

The technical potential for automation differs dramatically across sectors and activities.

by Michael Chui, James Manyika, and Mehdi Miremadi

As automation technologies such as machine learning and robotics play an increasingly great role in everyday life, their potential effect on the workplace has, unsurprisingly, become a major focus of research and public concern. The discussion tends toward a Manichean guessing game: which jobs will or won't be replaced by machines?

In fact, as our research has begun to show, the story is more nuanced. While automation will eliminate very few occupations entirely in the next decade, it will affect portions of almost all jobs to a greater or lesser degree, depending on the type of work they entail. Automation, now going beyond routine manufacturing activities, has the potential, as least with regard to its technical feasibility, to transform sectors such as healthcare and finance, which involve a substantial share of knowledge work.

These conclusions rest on our detailed analysis of 2,000-plus work activities for more than 800 occupations. Using data from the US Bureau of Labor Statistics and O*Net, we've quantified both the amount of time spent on these activities across the economy of the United States and the technical feasibility of automating each of them. The full results, forthcoming in

early 2017, will include several other countries,[1] but we released some initial findings late last year and are following up now with additional interim results.

Last year, we showed that currently demonstrated technologies could automate 45 percent of the activities people are paid to perform and that about 60 percent of all occupations could see 30 percent or more of their constituent activities automated, again with technologies available today. In this article, we examine the technical feasibility, using currently demonstrated technologies, of automating three groups of occupational activities: those that are highly susceptible, less susceptible, and least susceptible to automation. Within each category, we discuss the sectors and occupations where robots and other machines are most—and least—likely to serve as substitutes in activities humans currently perform. Toward the end of this article, we discuss how evolving technologies, such as natural-language generation, could change the outlook, as well as some implications for senior executives who lead increasingly automated enterprises.

UNDERSTANDING AUTOMATION POTENTIAL

In discussing automation, we refer to the potential that a given activity could be automated by adopting currently demonstrated technologies, that is to say, whether or not the automation of that activity is *technically feasible*.[2] Each whole occupation is made up of multiple types of activities, each with varying degrees of technical feasibility. Exhibit 1 lists seven top-level groupings of activities we have identified. Occupations in retailing, for example, involve activities such as collecting or processing data, interacting with customers, and setting up merchandise displays (which we classify as physical movement in a predictable environment). Since all of these constituent activities have a different automation potential, we arrive at an overall estimate for the sector by examining the time workers spend on each of them during the workweek.

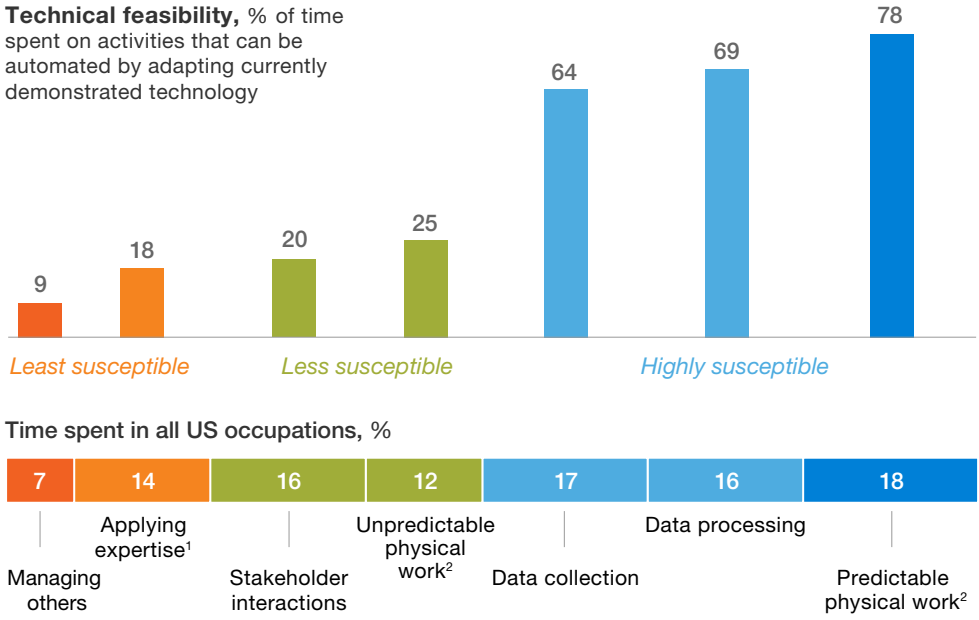
Technical feasibility is a necessary precondition for automation, but not a complete predictor that an activity will be automated. A second factor to consider is the cost of developing and deploying both the hardware and the software for automation. The cost of labor and related supply-and-demand dynamics represent a third factor: if workers are in abundant supply and significantly less expensive than automation, this could be a decisive argument against it. A fourth factor to consider is the benefits beyond labor

[1] For interim insights on our core findings, see Michael Chui, James Manyika, and Mehdi Miremadi, "Four fundamentals of workplace automation," *McKinsey Quarterly*, November 2015, McKinsey.com.

[2] We define "currently demonstrated technologies" as those that have already exhibited the level of performance and reliability needed to automate 1 or more of the 18 capabilities involved in carrying out work activities. In some cases, that level of performance has been demonstrated through commercially available products, in others through research projects.

Exhibit 1

Analyzing work activities rather than occupations is the most accurate way to examine the technical feasibility of automation.



In practice, automation will depend on more than just technical feasibility. Five factors are involved: technical feasibility; costs to automate; the relative scarcity, skills, and cost of workers who might otherwise do the activity; benefits (eg, superior performance) of automation beyond labor-cost substitution; and regulatory and social-acceptance considerations.

[1]Applying expertise to decision making, planning, and creative tasks.
[2]Unpredictable physical work (physical activities and the operation of machinery) is performed in unpredictable environments, while in predictable physical work, the environments are predictable.

substitution, including higher levels of output, better quality, and fewer errors. These are often larger than those 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 human contact. The potential for automation to take hold in a sector or occupation reflects a subtle interplay between these factors and the trade-offs among them.

Even when machines do take over some human activities in an occupation, this does not necessarily spell the end of the jobs in that line of work. On the contrary, their number at times increases in occupations that have been partly automated, because overall demand for their remaining activities has continued to grow. For example, the large-scale deployment of bar-code

scanners and associated point-of-sale systems in the United States in the 1980s reduced labor costs per store by an estimated 4.5 percent and the cost of the groceries consumers bought by 1.4 percent.[3] It also enabled a number of innovations, including increased promotions. But cashiers were still needed; in fact, their employment grew at an average rate of more than 2 percent between 1980 and 2013.

THE MOST AUTOMATABLE ACTIVITIES

Almost one-fifth of the time spent in US workplaces involves performing physical activities or operating machinery in a predictable environment: workers carry out specific actions in well-known settings where changes are relatively easy to anticipate. Through the adaptation and adoption of currently available technologies, we estimate the technical feasibility of automating such activities at 78 percent, the highest of our seven top-level categories (Exhibit 2). Since predictable physical activities figure prominently in sectors such as manufacturing, food service and accommodations, and retailing, these are the most susceptible to automation based on technical considerations alone.

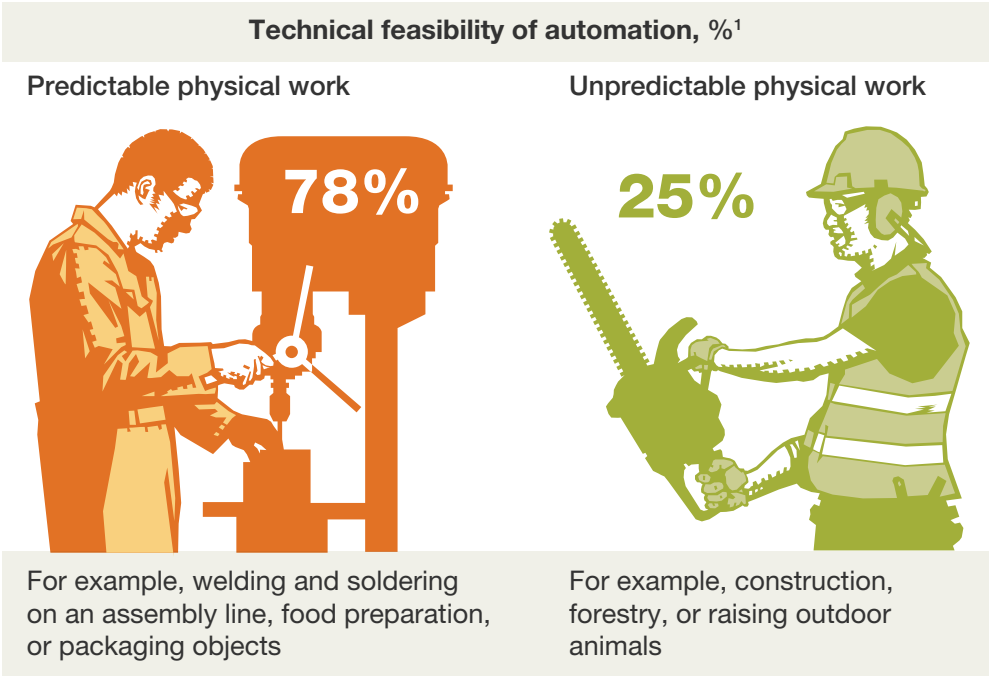
In manufacturing, for example, performing physical activities or operating machinery in a predictable environment represents one-third of the workers' overall time. The activities range from packaging products to loading materials on production equipment to welding to maintaining equipment. Because of the prevalence of such predictable physical work, some 59 percent of all manufacturing activities could be automated, given technical considerations. The overall technical feasibility, however, masks considerable variance. Within manufacturing, 90 percent of what welders, cutters, solderers, and brazers do, for example, has the technical potential for automation, but for customer-service representatives that feasibility is below 30 percent. The potential varies among companies as well. Our work with manufacturers reveals a wide range of adoption levels—from companies with inconsistent or little use of automation all the way to quite sophisticated users.

Manufacturing, for all its technical potential, is only the second most readily automatable sector in the US economy. A service sector occupies the top spot: accommodations and food service, where almost half of all labor time involves predictable physical activities and the operation of machinery—including preparing, cooking, or serving food; cleaning food-preparation

[3] Emek Basker, "Change at the checkout: Tracing the impact of a process innovation," *The Journal of Industrial Economics*, June 2015, Volume 63, Number 2, pp. 339–70.

Exhibit 2

It's more technically feasible to automate predictable physical activities than unpredictable ones.



[1]% of time spent on activities that can be automated by adapting currently demonstrated technology.

areas; preparing hot and cold beverages; and collecting dirty dishes. According to our analysis, 73 percent of the activities workers perform in food service and accommodations have the potential for automation, based on technical considerations.

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, like self-service ordering or even robotic servers. Solutions such as Momentum Machines' hamburger-cooking robot, which can reportedly assemble and cook 360 burgers an hour, could automate a number of cooking and food-preparation activities. But while the technical potential for automating them might be high, the business case must take into account both the benefits and the costs of automation, as well as the labor-supply dynamics discussed earlier. For some of these activities, current wage rates 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 an hour, a business case based solely on reducing labor costs may be unconvincing.

Retailing is another sector with a high technical potential for automation. We estimate that 53 percent of its activities are automatable, though, as in manufacturing, much depends on the specific occupation within the sector. Retailers can take advantage of efficient, technology-driven stock management and logistics, for example. Packaging objects for shipping and stocking merchandise are among the most frequent physical activities in retailing, and they have a high technical potential for automation. So do maintaining records of sales, gathering customer or product information, and other data-collection activities. But retailing also requires cognitive and social skills. Advising customers which cuts of meat or what color shoes to buy requires judgment and emotional intelligence. We calculate that 47 percent of a retail salesperson's activities have the technical potential to be automated—far less than the 86 percent possible for the sector's bookkeepers, accountants, and auditing clerks.

As we noted above, however, just because an activity can be automated doesn't mean that it will be—broader economic factors are at play. The jobs of bookkeepers, accountants, and auditing clerks, for example, require skills and training, so they are scarcer than basic cooks. But the activities they perform cost less to automate, requiring mostly software and a basic computer.

Considerations such as these have led to an observed tendency for higher rates of automation for activities common in some middle-skill jobs—for example, in data collection and data processing. As automation advances in capability, jobs involving higher skills will probably be automated at increasingly high rates.

The heat map in Exhibit 3 highlights the wide variation in how automation could play out, both in individual sectors and for different types of activities within them.[4]

ACTIVITIES AND SECTORS IN THE MIDDLE RANGE FOR AUTOMATION

Across all occupations in the US economy, one-third of the time spent in the workplace involves collecting and processing data. Both activities have a technical potential for automation exceeding 60 percent. Long ago, many companies automated activities such as administering procurement, processing payrolls, calculating material-resource needs, generating

[4] For a deeper look across all sectors in the US economy, please see the data representations from McKinsey on automation and US jobs, on public.tableau.com.

invoices, and using bar codes to track flows of materials. But as technology progresses, computers are helping to 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. And it's not just entry-level workers or low-wage clerks who collect and process data; people whose annual incomes exceed $200,000 spend some 31 percent of their time doing those things, as well.

Financial services and insurance provide one example of this phenomenon. The world of finance relies on professional expertise: 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 technical potential for automation is high. Insurance sales agents gather customer or product information and underwriters verify the accuracy of records. Securities and financial sales agents prepare sales or other contracts. Bank tellers verify the accuracy of financial data.

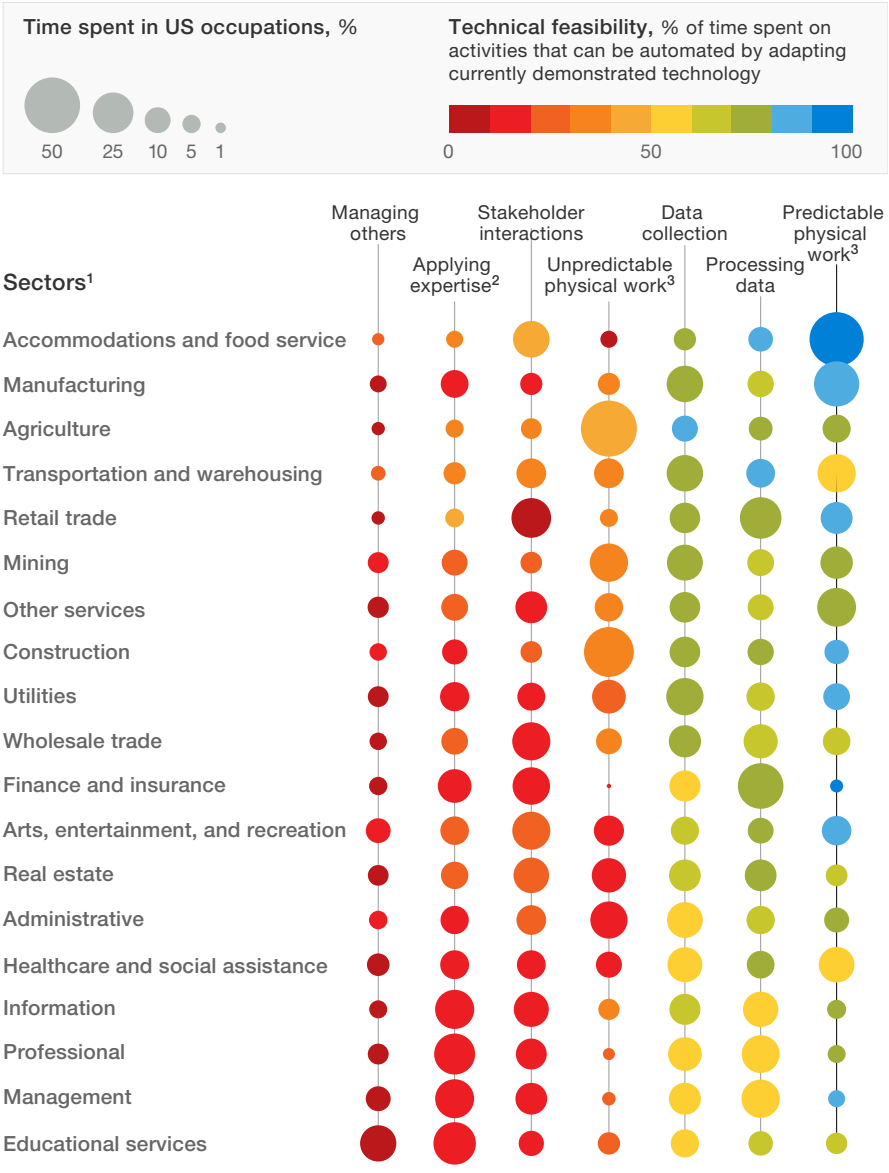
As a result, the financial sector has the technical potential to automate activities taking up 43 percent of its workers' time. Once again, the potential is far higher for some occupations than for others. For example, we estimate that mortgage brokers spend as much as 90 percent of their time processing applications. Putting in place more sophisticated verification processes for documents and credit applications could reduce that proportion to just more than 60 percent. This would free up mortgage advisers to focus more of their time on advising clients rather than routine processing. Both the customer and the mortgage institution get greater value.

Other activities in the middle range of the technical potential for automation involve large amounts of physical activity or the operation of machinery in *unpredictable* environments. These types of activities make up a high proportion of the work in sectors such as farming, forestry, and construction and can be found in many other sectors as well.

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 latter two activities are unpredictable largely because the environment keeps changing. Schoolchildren leave bags, books, and coats in a seemingly

Exhibit 3

Automation is technically feasible for many types of activities in industry sectors, but some activities can be more affected than others.



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[1]**Agriculture** includes forestry, fishing, and hunting; **other services** excludes federal-, state-, and local-government services; **real estate** includes rental and leasing; **administrative** includes administrative support and government administration; **healthcare and social assistance** includes private, state-government, and local-government hospitals; **professional** includes scientific and technical services; **educational services** includes private, state-government, and local-government schools.
[2]Applying expertise to decision making, planning, and creative tasks.
[3]Unpredictable physical work (physical activities and the operation of machinery) is performed in unpredictable environments, while in predictable physical work, the environments are predictable.

random manner. Likewise, in a hotel room, different guests throw pillows in different places, may or may not leave clothing on their beds, and clutter up the floor space in different ways.

These activities, requiring greater flexibility than those in a predictable environment, are for now more difficult to automate with currently demonstrated technologies: their automation potential is 25 percent. Should technology advance to handle unpredictable environments with the same ease as predictable ones, the potential for automation would jump to 67 percent. Already, some activities in less predictable settings in farming and construction (such as evaluating the quality of crops, measuring materials, or translating blueprints into work requirements) are more susceptible to automation.

ACTIVITIES WITH LOW TECHNICAL POTENTIAL FOR AUTOMATION

The hardest activities to automate with currently available technologies are those that involve managing and developing people (9 percent automation potential) or that apply expertise to decision making, planning, or creative work (18 percent). These activities, often characterized as knowledge work, can be as varied as coding software, creating menus, or writing promotional materials. For now, computers do an excellent job with very well-defined activities, such as optimizing trucking routes, but humans still need to determine the proper goals, interpret results, or provide commonsense checks for solutions. The importance of human interaction is evident in two sectors that, so far, have a relatively low technical potential for automation: healthcare and education.

Overall, healthcare has a technical potential for automation of about 36 percent, but the potential is lower for health professionals whose daily activities require expertise and direct contact with patients. For example, we estimate that less than 30 percent of a registered nurse's activities could be automated, based on technical considerations alone. For dental hygienists, that proportion drops to 13 percent.

Nonetheless, some healthcare activities, including preparing food in hospitals and administering non-intravenous medications, could be automated if currently demonstrated technologies were adapted. Data collection, which also accounts for a significant amount of working time in the sector, could become more automated as well. Nursing assistants, for example, spend about two-thirds of their time collecting health information.

Even some of the more complex activities that doctors perform, such as administering anesthesia during simple procedures or reading radiological scans, have the technical potential for automation.

Of all the sectors we have examined, the technical feasibility of automation is lowest in education, at least for now. 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 complex interactions with other people. Together, those two categories—the least automatable of the seven identified in the first exhibit—account for about one-half of the activities in the education sector.

Even so, 27 percent of the activities in education—primarily those that happen outside the classroom or on the sidelines—have the potential to be automated with demonstrated technologies. Janitors and cleaners, for example, clean and monitor building premises. Cooks prepare and serve school food. Administrative assistants maintain inventory records and personnel information. The automation of these data-collection and processing activities may help to reduce the growth of the administrative expenses of education and to lower its cost without affecting its quality.

LOOKING AHEAD

As technology develops, robotics and machine learning will make greater inroads into activities that today have only a low technical potential for automation. New techniques, for example, are enabling safer and more enhanced physical collaboration between robots and humans in what are now considered unpredictable environments. These developments could enable the automation of more activities in sectors such as construction. Artificial intelligence can be used to design components in engineer-heavy sectors.

One of the biggest technological breakthroughs would come if machines were to develop an understanding of natural language on par with median human performance—that is, if computers gained the ability to recognize the concepts in everyday communication between people. In retailing, such natural-language advances would increase the technical potential for automation from 53 percent of all labor time to 60 percent. In finance and insurance, the leap would be even greater, to 66 percent, from 43 percent. In healthcare, too, while we don't believe currently demonstrated technologies could accomplish all of the activities needed to diagnose and treat patients,

technology will become more capable over time. Robots may not be cleaning your teeth or teaching your children quite yet, but that doesn't mean they won't in the future.

As stated at the outset, though, simply considering the technical potential for automation is not enough to assess how much of it will occur in particular activities. The actual level will reflect the interplay of the technical potential, the benefits and costs (or the business case), the supply-and-demand dynamics of labor, and various regulatory and social factors related to acceptability.

LEADING MORE AUTOMATED ENTERPRISES

Automation could transform the workplace for everyone, including senior management. The rapid evolution of technology can make harnessing its potential and avoiding its pitfalls especially complex. In some industries, such as retailing, automation is already changing the nature of competition. E-commerce players, for example, compete with traditional retailers by using both physical automation (such as robots in warehouses) and the automation of knowledge work (including algorithms that alert shoppers to items they may want to buy). In mining, autonomous haulage systems that transport ore inside mines more safely and efficiently than human operators do could also deliver a step change in productivity.

Top executives will first and foremost need to identify where automation could transform their own organizations and then put a plan in place to migrate to new business processes enabled by automation. A heat map of potential automation activities within companies can help to guide, identify, and prioritize the potential processes and activities that could be transformed. As we have noted, the key question will be where and how to unlock value, given the cost of replacing human labor with machines. The majority of the benefits may come not from reducing labor costs but from raising productivity through fewer errors, higher output, and improved quality, safety, and speed.

It is never too early to prepare for the future. To get ready for automation's advances tomorrow, executives must challenge themselves to understand the data and automation technologies on the horizon today. But more than data and technological savvy are required to capture value from automation. The greater challenges are the workforce and organizational changes that leaders will have to put in place as automation upends entire business

processes, as well as the culture of organizations, which must learn to view automation as a reliable productivity lever. Senior leaders, for their part, will need to "let go" in ways that run counter to a century of organizational development.[5]

Understanding the activities that are most susceptible to automation from a technical perspective could provide a unique opportunity to rethink how workers engage with their jobs and how digital labor platforms can better connect individuals, teams, and projects.[6] It could also inspire top managers to think about how many of their own activities could be better and more efficiently executed by machines, freeing up executive time to focus on the core competencies that no robot or algorithm can replace—as yet.

[5] See Martin Dewhurst and Paul Willmott, "Manager and machine: The new leadership equation," *McKinsey Quarterly*, September 2014, McKinsey.com.

[6] See Aaron De Smet, Susan Lund, and William Schaninger, "Organizing for the future," *McKinsey Quarterly*, January 2016, McKinsey.com.

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