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Digitally-enabled automation and artificial intelligence:

Shaping the future of work in Europe's digital front-runners

October 2017

Preface

Technology in many ways is perfectly conceived to operate in the workplace, bringing an ability to operate around the clock at increasing levels of accuracy and productivity. Since the Industrial Revolution, machines have been the ideal colleague, performing some of the most mind-numbing tasks and freeing up human partners to do more interesting and productive things. However, in the near future, new digital technologies are set to take the next step, graduating from the factory floor to the boardroom and applying themselves to more complex, cognitive activities. Technologies such as artificial intelligence (AI) are a game changer for automation in the workplace. Like ambitious young go-getters, they promise to take on more responsibility and make better decisions, and the implications for workers, companies, and policy makers are significant and pressing.

The impact of new digital technologies on the labor market has led to the coining of the phrase “technological unemployment,” which describes a view of how the industrialization of the workplace may play out. However, that perspective ignores the other side of the technological coin, which is that automation also creates jobs and brings a positive economic impact from its ability to boost innovation and productivity, and offers advances in fields including healthcare, retail and security (see appendix for case examples for how technology will affect both users and employers). This report is an attempt to provide a long-term view of how that balance may develop, *based on scenarios of how digital automation and AI will shape the workplace, and calibrated to sensitivities around the economy, productivity, job creation and skills*.

Our key insight is that in the past technology has been a major boost to productivity, affecting the structure of employment but having little negative impact, or even a positive effect, on total net employment. In the next ten to 15 years, the new wave of digital automation and artificial intelligence will likely have the same kind of impact, creating jobs and generating value through increased productivity. Some jobs will be displaced, and more tasks within jobs will change, suggesting the key challenge for policy makers will be to create the right mechanisms around training and education to ensure a fast and smooth transition to adapt to a different skill structure in the future.

While we expect the structure of the broader work world will evolve, this report focuses on employment by companies, rather than self-employment, and on the period up to 2030, at which point we expect that the new automation process will be ongoing. Our research is focused on nine “digital front-runners” in Northern Europe (Belgium, Denmark, Estonia, Finland, Ireland, Luxembourg, Netherlands, Norway, and Sweden), which we have chosen because they are relatively enthusiastic adopters of digital technology, and are ahead of peers in the use of robotics, machine learning and AI. We expect that the likely dynamics of automation and AI diffusion and the related evolution of labor markets in the digital front-runners may provide lessons for many countries. Our research shows significant value in embracing AI and automation, but sees a requirement for new skill sets among employees and a policy response around education, training and the social contract.

The material herein is based on extensive primary research and secondary sources. The research leverages an enterprise survey on how firms are integrating new technologies in their business processes, a methodology developed by the McKinsey Global Institute for identifying automation potential. We would also like to thank the many experts from the public, private, and social sectors who provided insights and helped advance our thinking. In particular, we would like to thank Google for its contributions, including insights from discussions with members of its Growth Engine initiative.

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In brief

Digitally-enabled automation and artificial intelligence (AI) are set to become the primary drivers of the next technological revolution. To gauge the potential impact on companies, employees and society, this report focuses on nine European “digital front-runners”—Belgium, Denmark, Estonia, Finland, Ireland, Luxembourg, Netherlands, Norway, and Sweden. We find that automation and AI bring significant benefits, including new jobs and increased productivity. However, employers, employees and policy makers face challenges in managing the shift to a new economy, which requires significant reskilling and a socially responsible transition..

1. Digital technologies in the past brought jobs, skill development, and rising productivity in digital front-runner countries

- Companies in digital front-runner countries had digitized around 25 percent of their business systems by 2016.
- Technology diffusion contributed 0.4 to 0.6 percentage points, or around 30 percent, of digital front-runner GDP growth between 1990 and 2016, worth around €15 billion a year.
- Digital technology replaced jobs in digital front-runner countries at a rate of about 120,000 jobs a year between 1999 and 2010, and boosted employment by around 200,000 jobs a year, creating positive net employment of 80,000 jobs per year.
- Of the 200,000 jobs created, around 80,000 were directly in digital and ICT technology, with many that were unimaginable a few years ago (e.g., digital marketers, big data analysts). Some 120,000 additional jobs were created from the indirect effects of reinvesting productivity gains in the economy.
- More than half of new jobs were high-skill, and around 40 percent of jobs in digital front-runners, or 12 million, are currently high-skill.

2. A more productive future for a resilient labor market

New technologies might accelerate productivity growth:

- New digitally-enabled automation and AI has the potential to bring an uplift in digital front-runner country GDP growth of about €550 billion, or about 1.2% per year from 2016-2030.
- Roughly half of productivity gains will come from jobs being lost as a result of automation, while the rest will be from new products, services and opportunities enabled by new technologies.

Larger rotation in occupations/tasks, but limited risk of mounting technology unemployment

- Tasks with the technical potential to be automated in the digital front-runner countries represent 44 percent of current working hours.
- Less than 20 percent of jobs (those with 70 percent of automatable tasks or 19 percent of working time) may be made directly obsolete. The balance of 25 percent of working hours will be divided among 80 percent of employees, and so will only impact a small proportion of their current tasks.
- Diffusion of new digitally-enabled automation and AI technologies will proceed at the same pace as the previous digital technology cycle, implying that two thirds of the potential effect of technology available today will be felt by 2030.
- At the predicted pace of diffusion there is limited risk of mounting unemployment among the digital front-runners. About 300,000 jobs may be displaced every year, or roughly twice the number as in the past. Automation and AI may also create 320,000 jobs a year, without sacrificing wages or working hours.
- A third of new employment will likely be new job categories, and two-thirds will probably be (task-adapted) jobs created as a result of output expansion.

3. A new skill structure for the future

- By 2030, and without a change in industrial policy, digital technologies will continue to accelerate the shift from sectors such as trade and manufacturing to services.
- The digital part of the economy will account for 19 percent of jobs in digital front-runner countries, up from 8 percent in 2017.
- There will be a major shift in the type of skills needed. Technological, cognitive and new creative and interpersonal skills will account for nearly half of work activities by 2030, compared with 37 percent in 2017.

4. A five-point agenda can support the future of work

- The digital front-runner countries are in a position to leverage automation to increase economic growth and support employment at least at current levels. We propose five strategic priorities:
    1. **Work to maintain digital front-runner digital leadership status.** Encourage speedy adoption by removing barriers to innovation and upgrading infrastructure.
    2. **Support local AI and automation ecosystems.** Encourage experimentation, nurture talent, and foster public R&D.
    3. **Educate and train for the future of work.** Reorient education systems, leverage automation technologies in education, emphasize life-long learning, and support on-the-job training.
    4. **Support worker transition.** Experiment with socials models, and assess hours worked.
    5. **Shape the global policy framework.** Focus on future policy, addressing issues including cyber-security, privacy, and a code of ethics for technology.

Automation is a major opportunity, but it must be managed

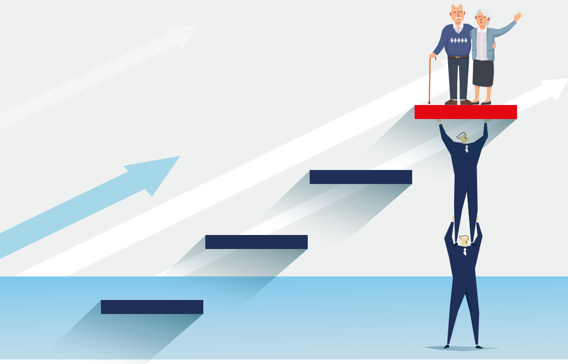
1

Nine Northern European countries are digital front-runners that are well positioned to exploit automation ...

Highest level of digital capabilities in Europe and **75%** are positive toward automation

2

... and automation could help address the economic challenges caused by an aging population



+1.2% GDP per capita growth increase from automation

3

... employment expected to be resilient, as job creation offsets job substitution ...

~4.5m jobs replaced and created by automation by 2030

4

... however, there are five critical implications for policy makers to manage

A More demand for digital solutions, **doubling digital labor demand** towards 2030

B Shift to **new skill mix** requiring more technical, social and creative skills

C **Transition of workers** from declining to growing sectors, as jobs are replaced and created

D **New market opportunities** can make up half of the gains from automation

E Increase in **international competiveness** due to higher productivity

€ 550 billion
additional GDP growth by 2030

(…) Sensitivity[1]

Automation will boost economic growth in the midpoint scenario

Economic impact, per year	Historical trend 1990-2016, %	Baseline without automation 2016-2030, %	Economy with automation[3] 2016-2030, %
GDP growth	2.1%	1.1%	2.3% (±1.1 PP)
GDP per capita growth	1.6%	0.7%	1.9% (±1.1 PP)
Productivity growth driven by technology	0.4%	0.1%	1.2% (±0.9 PP)

Automation requires the workforce to be reskilled to generate inclusive growth

Labor force impact	Historic trend 1990-2016, %	Baseline without automation 2016-2030, %	Economy with automation[3] 2016-2030, %
Reskilling need	1.4%	1.4%	2.7%
Skill inequality[2]	5%	2%	13%
Share of digital jobs[4]	8%	8%	19%
Share of tasks less prone to automation	39%	39%	49%

1 PP = percentage points
2 Skill inequality is defined as percentage point difference in unemployment rate between high skilled and medium/low skilled
3 Results for the midpoint scenario, which is one of several possible scenarios analyzed
4 Digital jobs or digitally-affected jobs

Introduction

One of the defining issues of our time is the relationship between labor and technology. The application of the latter is accelerating in the workplace and expanding from routine tasks to complex, cognitive activities that require a high degree of skill and judgment. As new digitally-enabled automation and artificial intelligence (AI) play a growing role, there is rising concern over the possible impact on employment, and that the pattern of the past, which saw new jobs created in place of those made obsolete, may be set to change.

Technology and employment: Will the virtuous cycle break?

In previous generations, technology was demonstrably a "good thing," leading to productivity gains that were manifested in rising wages, better working conditions, and higher levels of employment. A third of new jobs created in the United States in the past 25 years did not exist 25 years ago.[1] However, when it comes to the accelerating impact of machines in the workplace, there is concern the past may not be an accurate indicator of the future.

Certainly, the impact of tech is becoming more visible. In Japan, sushi chain Kura has replaced chefs and staff with robots in more than 250 restaurants, and a new hotel, called Henn-na, is staffed entirely by machines. In Mercedes factories in Germany, robots create individualized cars, while Amazon in the United States has switched to machine workers in its key logistics centers, recently reducing click to ship from 60 to 15 minutes. Automation seems to be replacing humans everywhere, and according to one recent study nearly 50 percent of employment is at risk in the long term.[2] Not surprisingly, that is leading to public debate. Another study shows some 72 percent of the people in the European Union fear that robots may take their jobs.[3]

Previously, as machines have taken on specific tasks and processes, humans have found alternative sources of employment, with new jobs directly created and arising from productivity gains. In the 200 years since the Industrial Revolution, there has been little evidence that machines have led to mass unemployment. But now there are signs that the benign partnership between automation and employment may be fracturing. In the economically challenged years since the financial crisis, wages have failed to rise for most people.[4] Jobs in the middle of the pay scale—the majority—have come under particular pressure, leading to job polarization and stalling the progress of the middle class.[5]

In 1930, the British economist John Maynard Keynes coined the term "technological unemployment," describing a situation in which innovation that economizes the use of labor outstrips job creation.[6] Keynes described this as a "temporary phase of maladjustment," meaning there may be a lag between automation's immediate impact and employees' return to full-time work. During that period, humans must consider their options, seek retraining, and eventually find new occupations.

Keynes's valuable contribution was that the positive or negative impact of automation hinges critically on smooth job transitions and new job creation. In short, the task of reskilling and educating is crucial and will be the difference between employment creation and reduction in the years ahead.

1 Jeffrey Lin, "Technological adaptation, cities, and new work," Review of Economics and Statistics, volume 93, no. 2, May 2011, pp. 554–574.

2 Carl Benedikt Frey and Michael A. Osborne, The future of employment: How susceptible are jobs to computerisation? Oxford Martin Programme on Technology and Employment, September 2013, oxfordmartin.ox.ac.uk.

3 European Commission, Attitudes towards the impact of digitisation and automation on daily life, Special Eurobarometer 460, May 2017, ec.europa.eu.

4 João Paulo Pessoa, and John Van Reenen, "Wage growth and productivity growth: The myth and reality of 'decoupling,'" CentrePiece (London School of Economics Centre for Economic Performance), no. 401, December 2013, lse.ac.uk. Wage decoupling has been especially significant in the United States.

5 Maarten Goos, Alan Manning, and Anna Salomons, "Explaining job polarization: Routine-biased technological change and offshoring," American Economic Review, volume 104, no. 8, August 2014, pp. 2509–2526.

6 John Maynard Keynes, "The economic possibilities for our grandchildren (1930)," in Essays in Persuasion (London: Macmillan, 1931). The essay is available online at www.econ.yale.edu/smith/econ116a/keynes1.pdf.

The future of work in the digital front-runners of northern Europe

In seeking to model and analyze the dynamics around technology, productivity and employment (see sidebar "The research in this report"), this report focuses on nine Northern European countries that are among the world's most advanced digital economies: Belgium, the Netherlands, Luxembourg, Denmark, Finland, Norway, Sweden, Estonia and Ireland. The so-called digital front-runners score highly on digital integration and have launched numerous public initiatives to boost the digital economy. The Netherlands was the first country to install a nationwide network to enable the Internet of Things. Estonia is a champion of digitizing public services. Finland is experimenting with a universal basic income to manage redundancy. The digital front-runners are also home to a higher-than-average number of companies currently adopting AI and automation technologies (14 percent versus 10 percent in the United States), according to McKinsey research. Meanwhile, some 75 percent of the digital front-runner population have a positive view of automation, higher than the EU average of 61 percent.[7]

A challenging macroeconomic outlook—with shifting dynamics

In most advanced economies the workforce is shrinking, and in the digital front-runners it is set to decline to 43 percent of the population by 2040, compared with 47 percent in 2017. A smaller workforce means GDP growth cannot be maintained without higher productivity, but productivity growth in recent years has slowed.

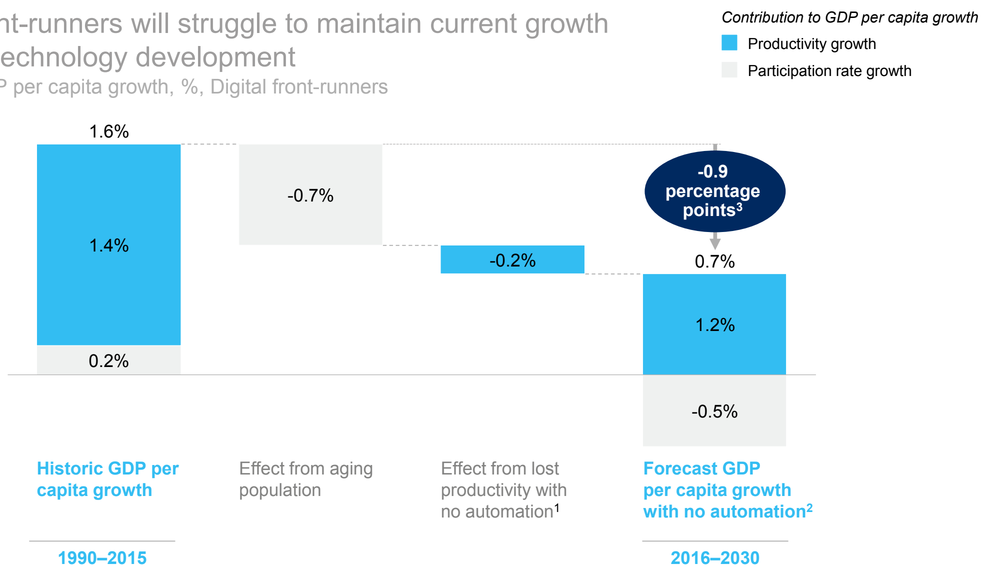
In the digital front-runners, productivity growth was 1.4 percent between 1990 and 2015, compared with 2.7 percent between 1965 and 1990, and it is set to slow further.[8] That failure to produce much more for the same hours worked raises significant questions around the future of economic growth and prosperity (Exhibit 1).

Automation may be a material part of the solution to the productivity conundrum. Machines can perform some work activities more accurately than humans and at a lower cost. More activity, higher quality and less downtime mean that companies can grow faster, and create new products and services, leading to increased output and better economic performance.

Exhibit 1

The digital front-runners will struggle to maintain current growth rates without technology development

Contribution to GDP per capita growth, %, Digital front-runners



1 Historic contribution to productivity growth from automation (0.5% per year) is included in first part of forecast (2016–2020) but excluded from last part of forecast (2021–2030).
2 Historic growth and consensus forecast 2016–2020 based on data for the European Union.
3 Growth decrease by country: Ireland -3.4%; Estonia -3.4%; Luxembourg -1.7%; Netherlands -1.0%; Sweden -0.8%; Norway -0.7%; Belgium -0.6%; Denmark -0.5%; Finland -0.5%

Source: OECD, UN, Eurostat, McKinsey analysis

7 European Commission, Attitudes towards the impact of digitisation and automation.

8 While the financial crisis has contributed to the slowdown of productivity growth, a historical perspective shows that decrease in productivity growth follows a trend that goes beyond the financial crisis. Part of the explanation may be that it is more difficult to make productivity gains in a service-based economy.

Recent research has demonstrated that in 17 developed countries, the first generation of robots, applied mostly in manufacturing, led to a rise in labor productivity of 0.4 percent a year, while digitization has led to an annual increase of roughly 0.6 percentage points.[9]

Is this time different?

The past may be a guide to the future, and the impact of technology has generally been positive. We estimate technology has been directly or indirectly responsible for 0.1 percent to 0.5 percent of net employment growth per year in the digital front-runners in recent decades.[10]

However, if the pace of innovation accelerates and automation spreads to more sectors of the economy, there is a question of whether it is possible to create enough new jobs (particularly in the dominant and economically crucial middle segment) over a short period of time. As policy makers consider the possible negative consequences, five considerations may provide some comfort:

1. What is the alternative path to renewed growth? Productivity is slowing down in developed countries and the population is ageing. Resisting technology is possibly equivalent to limiting an option to sustain growth.

2. Technology diffusion takes time. We estimate that 44 percent of time spent in work in the digital front-runner countries has the potential to be automated, a lower estimate than previously thought. Even if AI technologies are developing more advanced cognitive abilities, they are still currently limited. The Polanyi paradox, named after author Michael Polanyi, still applies, at least in part. It says there is a tacit dimension of human intellect (tradition, inherited practices, implied values and judgments) that computers lack.[11] Further, technology's potential may take more time to materialize. Today, 25 years after the first wave of digital technology, some 30 percent of companies in digital front-runner countries have yet to use it across the full spectrum of business processes. The is limited evidence that adoption will accelerate for the new generation of technologies, and in fact a large number of companies say they are reluctant to invest too quickly. On the demand side, there is also social resistance to technology. For example, many passengers are wary of pilotless planes, preferring that humans stay in the cockpit.[12]

3. The rollout of automation will lead to higher productivity, the ultimate driver of economic well-being. Productivity gains, at least in part, may be reinvested in economies to create new opportunities and jobs.

4. Technology will often complement rather than replace jobs. The first generation of robotics showed technology can expand business without replacing jobs, e.g., in mining allowing deeper excavations where humans cannot travel. In one example of a collaborative approach, Swedish-Swiss multinational ABB now produces so-called YuMi robots, which are designed to work with, rather than replace, humans in manufacturing.

5. Technology diffusion is often accompanied by growth in skills. Technology often replaces risky and repetitive tasks, leading to better jobs and a broader skill set. There is a challenge in acquiring a more advanced skills, but more skills are also correlated with a better work experience and higher productivity.[13]

Scope and methodology

This report aims to enable a better understanding of the relationships between technology, productivity and work, taking into account key sensitivities such as skill transitioning and the dynamics around job loss and job creation.[14]

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9 Stephen Ezell, "The impact of digitalization and robotization on employment," presentation at "The Next Production Revolution," OECD conference in Stockholm, November 18, 2016, available from Information Technology and Innovation Foundation, itif.org; Georg Graetz and Guy Michaels, "Robots at work," CEP Discussion Paper no. 1335, Centre for Economic Performance, March 2015, cep.lse.ac.uk.

10 Gregory, Terry, Anna Salomons, and Ulrich Zierahn. "Racing with or against the machine? Evidence from Europe." Discussion paper no. 16-053. Centre for European Economic Research (ZEW), July 2016, zew.de.

11 Michael Polanyi, The Tacit Dimension (Chicago: University of Chicago Press, 1966).

12 Robots flying planes? Boeing projects a demand for nearly 1.2 million new pilots and technicians, ROBOTENOMICS , blog post

13 Employee training is worth the investment; go2HR, 2017

14 A future that works: Automation, employment, and productivity, McKinsey Global Institute, January 2017, McKinsey.com.

Among new digital technologies, we focus on automation technologies, mostly enhanced by artificial intelligence, defined as "narrow AI," which is capable of performing a single task (see sidebar "Artificial intelligence at a glance"). We omit "general AI," which mimics human intellectual capabilities across numerous tasks and which we do not expect will be in the mainstream by 2030.

Artificial intelligence at a glance

Artificial intelligence is expected to support a new wave of automation. Our definition is based on an ability to learn from experience, aided by big data architecture and a new generation of self-learning algorithms. The relevant class of AI technologies include advanced neural network machine learning techniques, smart robotics, natural-language processing, computer vision, autonomous vehicles and virtual agents.

McKinsey Global Institute estimates that total investment in AI to date amounts to between $25 billion and $40 billion, with the largest amount directed toward machine learning.[15] While the capabilities of AI are growing, it has some limitations. For example, it is highly dependent on the data sets on which it is trained.

The research in this report

The predictions in this report are based on scenario analysis, calibrated to the recent impact of technology, and on primary research into technology uptake in the digital front-runners.

The research is based on a two-step approach, considering the past and future of automation and work. We seek to untangle the historical links between technology, productivity and employment, referencing the most recent literature and covering multiple time periods, geographies and technologies. We look at broad technologies that perform routine tasks, as well as the first generation of digital technologies and CAD-robotics. For early evidence on how new automation technologies may play out, we focus on a specific set of AI applications—those that involve self-learning and big data.

We aim to create a perspective on the future of work by uniting two analyses. We leverage the model developed by McKinsey Global Institute to analyze the labor-substitution effects of automation across 2,000 activities in more than 800 occupations in the digital front-runners. The model allows us to determine the potential for automating working hours across current occupations, sectors and countries and provides a perspective on the likely pace of automation. We also rely on primary research on adoption patterns in the digital front-runners and expected business cases.

Using these data sets, we explicitly model a pro forma of product and labor markets, aiming to understand the dynamics of adoption, productivity, and employment linked to digital and enhanced by new automation technologies.

For our simulations, we take a conservative view of employment. First, we consider only the impact of technology; other labor-market dynamics are excluded, even if they might boost demand for labor (one-third of new job categories in recent decades were not related to technology). Further, we consider that employees will continue on the same path of wage growth as in the past. In other words, technical substitution of labor in favor of more automation is assumed to play out in full. The interested reader is referred to the technical appendix for a more comprehensive description of the methodology.

15 Artificial intelligence: The next digital frontier?, McKinsey Global Institute, discussion paper, June 2017, McKinsey.com.

Attitudes to automation in the digital front-runner countries

The digital front-runners have several common characteristics that affect their citizen's attitudes to automation and its adoption.

Small, open economies

The digital front-runners are small, open economies, relying on trade and participation in international value chains. Most are characterized by well-developed social-security systems, with modest unemployment, which could minimize the potentially negative impact of automation, but they have also seen a recent slowdown in productivity growth (Exhibit 2).

Digitally advanced

Several measures place our digital front-runners ahead of other European countries in terms of digitization. In the European Commission's latest Digital Economy and Society Index, Denmark is ranked number one, and the average score for the nine digital front-runners is 50 percent higher than for the five largest European countries (France, Germany, Italy, Spain, and the United Kingdom), which we refer to the 'Big 5'. The digital front-runners are also ahead on new automation and AI technologies. Almost 20 percent of companies have implemented AI at scale, and another 30 percent are piloting at least one technology (Exhibit 3). Likewise, citizens of digital front-runners have the most positive view on automation of European countries, with six (of eight countries, as Norway was not included in the EU survey) in the top 10 in terms of sentiment (Exhibit 4). In Denmark, the Netherlands, and Sweden, less than 20 percent of the population have a negative view of robots and artificial Intelligence—half the European average.

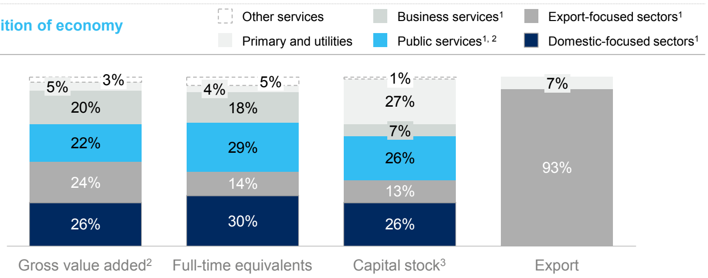
Exhibit 2

The aggregate digital front-runner economy at a glance

Economy stylized facts

- GDP: **~€2,800 billion** in 2016 (~16% of EU including Norway)
- Historic GDP growth: **2.4%** for 1990–2016
- Historic productivity growth: **1.4%** for 1990–2016
- Export fraction of GDP: **71%** in 2016
- Population: **~61 million** in 2016 (~12% of EU including Norway)
- Employee base: **~28.8 million**
- Unemployment: **~6.8%**

Composition of economy
%, 2016

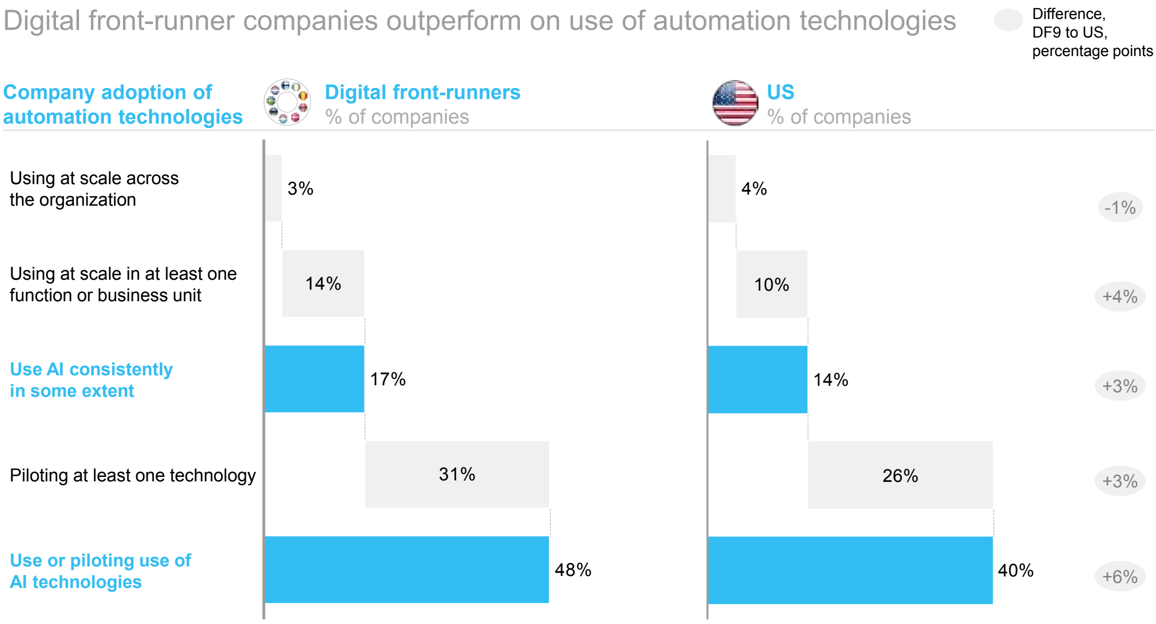


1 Business services include financial services and professional services. Public services include public education and human health and social services. Export-focused sectors include manufacturing and information and communications technology. Domestic-focused sectors include construction, trade, transport and hotels and restaurants. Real estate is excluded.
2 Value of output less the value of intermediate consumption. As public output value is not determined by market forces, the gross value added equals the sum of compensation of employees, consumption of fixed capital, other taxes less subsidies on production, and (an often small amount of) net operating surplus.
3 Capital data do not include Estonia, Ireland, or Sweden.

Source: OECD, McKinsey

Exhibit 3

Digital front-runner companies outperform on use of automation technologies



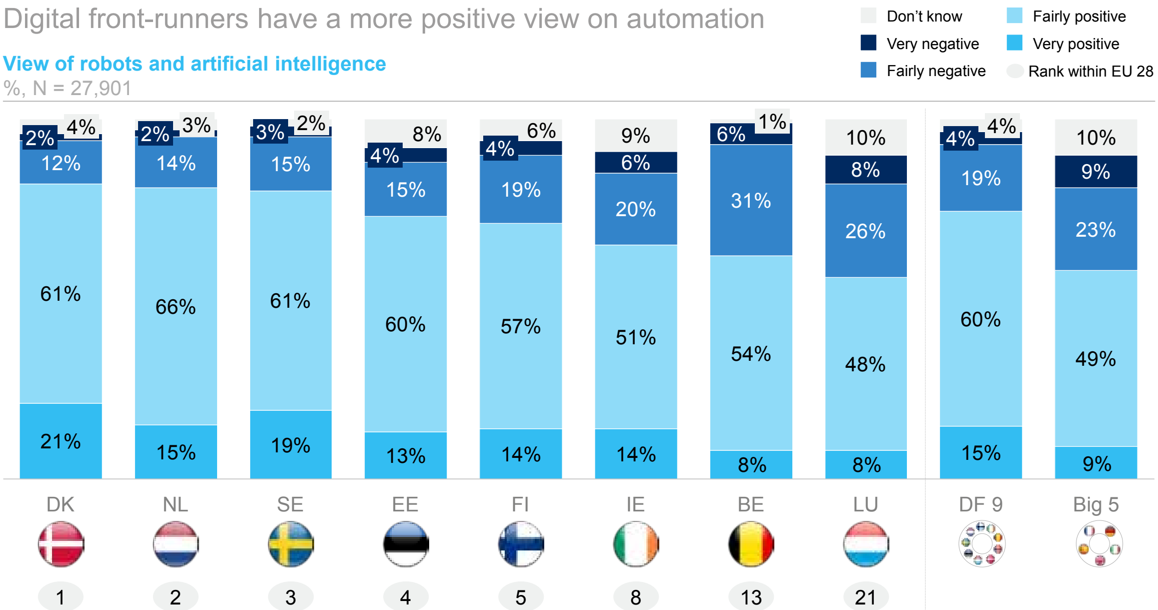
Source: McKinsey survey on AI adoption, McKinsey analysis

Exhibit 4

Digital front-runners have a more positive view on automation

View of robots and artificial intelligence

%, N = 27,901



Source: EU Commission (2017)

1. Automation in the past brought jobs, skill development, and rising productivity

A history of significant shifts in labor markets and rising employment

Employment in digital front-runner countries grew to around 29 million in 2016, from 20 million in the mid-1960s, and unemployment has remained steady at a relatively low level.

The labor market has shown that it can absorb significant shocks (Exhibit 5). One example on the supply side is the impact of female employment: the female participation rate rose to 73 percent in 2016, compared with 40 percent in 1960. That influx raised the proportion of the population at work to 77 percent, from 62 percent in the 1950s. On the demand side, manufacturing has seen a reduction in labor requirements of around 0.4 percentage points per year over the past 50 years. However, this has been more than compensated for by a rise in service-based employment.

Employment growth has been supported by a decline in working hours per week. For every percentage point of productivity growth in the digital front-runners, there has been some decline in working time per employee. People work 11 hours less per week (a decline of about 25 percent) compared with half a century ago. However, most of the declines came before 1980.

Slowdown in productivity growth

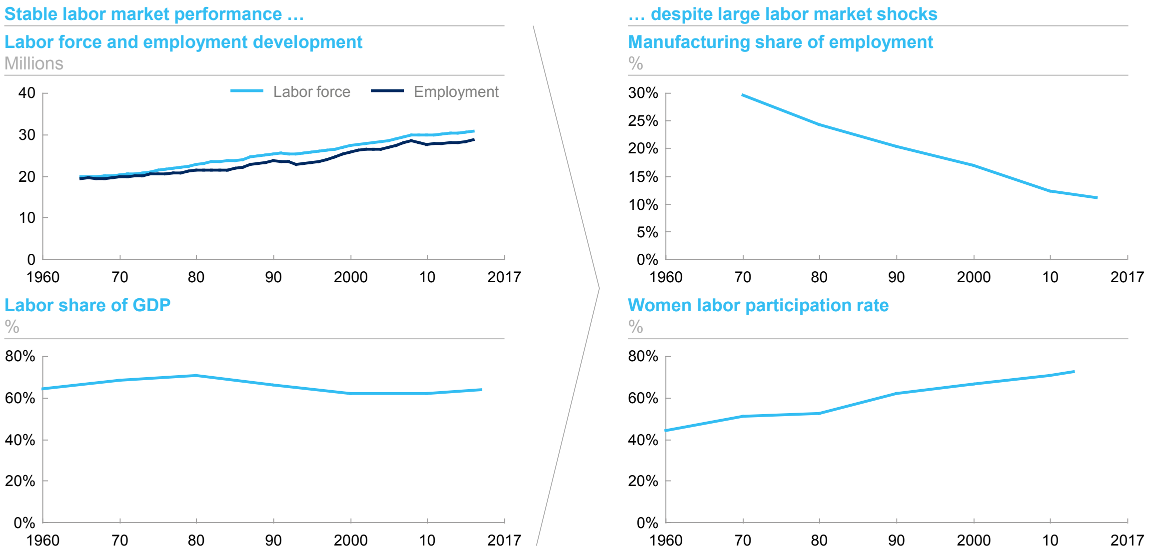
While productivity growth has been positive over the long term, it has abated in the recent period. Since 2005, productivity growth has averaged less than 1 percent a year, in part due to the impact of the financial crisis, compared with 3 percent to 4 percent a year in the 1960s and 1970s. Another explanation for slower growth is the transition from the dominance of highly productive manufacturing to less productive services. Economists predict around 1 percent of productivity growth in the digital front-runners over the coming years.[16]

Job polarization

The skill and education mix has changed. High-skill jobs, requiring more education, make up 40 percent of the

Exhibit 5

Digital front-runner labor markets have absorbed large shocks



Source: OECD, The Conference Board, EU Klems, Eurostat, AMECO, McKinsey

16 Compendium of Productivity Indicators, OECD, 2017.

total today, compared with 28 percent in 1998. Among the digital front-runners, Ireland has seen the biggest increase in high-skill jobs.[17]

Middle-paid jobs have tended to be displaced, with the biggest decline in Ireland, which saw a 15 percent fall between 1993 and 2015. Low-paid and high-paid jobs, meanwhile, have been less affected (Exhibit 6). The strong impact on the middle segment reflects the skills required for those jobs, which depend more on physical capabilities. We estimate that the fraction of time spent on physical tasks in the digital front-runners fell by 0.6 percent a year between 2003 and 2016. Conversely, the amount of time spent on problem solving and interaction skills rose by 0.2 percent a year.

The link to technology: Acceleration of trends

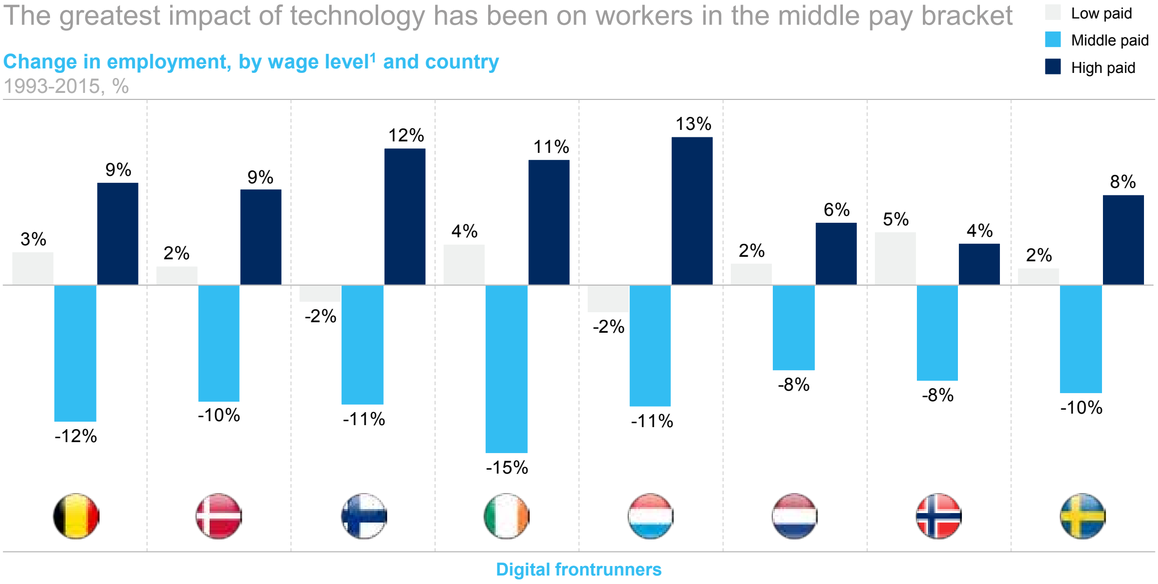
Technology has, over a long period of history, been seen as a threat to workers. In the early 19th century, English weavers known as Luddites destroyed machinery that threatened their jobs in cotton and wool mills.[18] Over the past century, the role of workers has been expected to diminish "in the same way that the role of horses in agricultural production was first diminished and then eliminated by the introduction of tractors," in the words of Nobel laureate Wassily Leontief.[19]

Certainly, technology displaces jobs, and in the United States there has not been a decade since the 1850s in which it did not do so.[20] One recent study claims that every robot makes as many as eight jobs obsolete.[21]

Exhibit 6

The greatest impact of technology has been on workers in the middle pay bracket

Change in employment, by wage level[1] and country
1993-2015, %



1 Based on 2-digit ISCO codes, creating 21 occupations: low paid are the 4 occupations with lowest mean wage, high paid the 8 highest-paid occupations, and middle paid the remaining 9 occupations.
Source: Goos, Manning, and Salomons (2014); Autor (2015); OECD Employment Outlook (2017)

17 Eurostat.

18 Other examples from history: In 1927, US. Labor Secretary James Davis expressed concern about automation replacing labor. In 1964, US president Lyndon Johnson commissioned the Blue-Ribbon Presidential Commission on Technology, Automation, and Economic Progress.

19 Wassily Leontief, "National perspective: The definition of problems and opportunities," in The Long-Term Impact of Technology on Employment and Unemployment: A National Academy of Engineering Symposium, June 30, 1983 (Washington, DC: National Academies Press, 1983).

20 Robert D. Atkinson and John Wu, False alarmism: Technological disruption and the U.S. labor market, 1850–2015, Information Technology and Innovation Foundation, May 2017, itif.org.

21 Acemoglu, Daron, and Pascual Restrepo, "Robots and jobs: Evidence from US labor markets," NBER Working Paper no. 23285, National Bureau of Economic Research, March 2017, nber.org.

However, technology also creates new job categories, and new job opportunities as the result of productivity increases reinvested elsewhere. Economy-wide, this can be material; between 1990 and 2016 in the digital front-runner countries, we estimate that technologies that performed routine tasks contributed 0.4 percent per year of output growth, or about 30 percent of the total, and 0.2 percent per year, or 33 percent, of total employment growth (Exhibit 7). This is all the more notable given that the information and communication technologies (ICT) sector accounted for just 5 percent of employment in digital front-runner countries in 2016.

Other studies have shown that robotics contributed 0.37 percentage points of GDP growth per year worldwide between 1993 and 2007, with limited evidence of net job destruction. The first generation of digital technologies contributed 0.6 percentage points of productivity, or about 0.2 percentage points of employment, per year between 2004 and 2008, in the Euro-27 countries.[22]

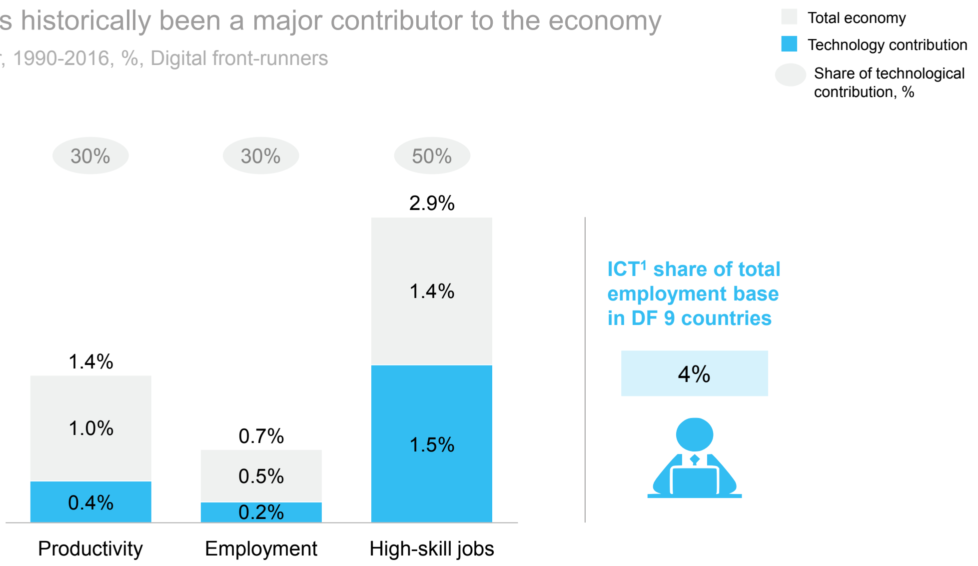
Increased productivity is defined by more efficient use of resources, which is the reason it challenges human employment. But technology also creates new job categories—virtual assistants, digital marketing and big data analysts are examples—and contributes to wider employment opportunities.[23] In the digital front-runners, we estimate that roughly half the impact of digital technologies on productivity is the consequence of the direct impact of technology (reducing employment), and the rest comes from a wider flowering of opportunities.

Indirect impacts can be in the sector where technology is adopted or where sectorial productivity gains are reinvested. Among examples, downstream German electronics companies have benefited from robotics in car manufacturing. In consumer markets, falling prices mean that products and activities that were previously too expensive have become affordable, allowing people to consume more. As economist Milton Friedman noted, "Human wants and needs are infinite, and so there

Exhibit 7

Technology has historically been a major contributor to the economy

Growth rate per year, 1990-2016, %, Digital front-runners



1 ICT short for 'Information and communications technology'
Source: Eurostat, McKinsey analysis

22 Contribution of robotics found in an analysis of robotics across 14 industries in 17 developed countries. Graetz and Michaels, "Robots at work." Contribution of digital technologies found in Ezell, "The impact of digitalization and robotization on employment."

23 Virtual assistants provide remote assistance for managers and business owners who may not be able to afford a full-time executive assistant. Thanks to the Internet, the virtual assistant can be based almost anywhere in the world and provide services to multiple clients, thereby reducing costs.

will always be new industries, there will always be new professions."

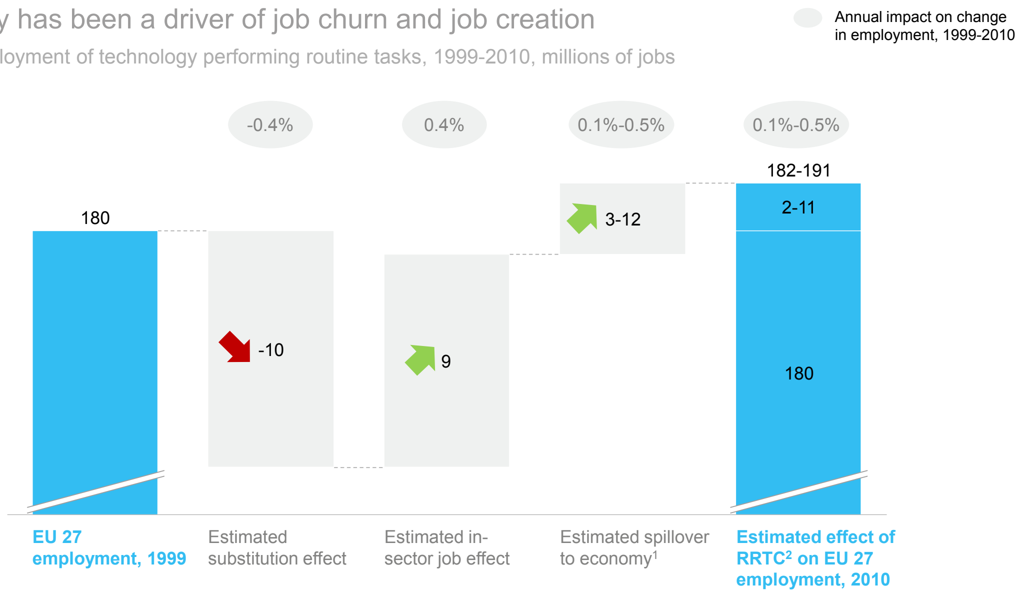
Cross-sectorial effects are an important compensation for the early effect of labor substitution. A study from 1997 to 2010 found that European business sectors adopting technologies that perform routine tasks first reduced jobs by about 10 million (out of 180 million jobs), but the resulting increase in competitiveness in due course almost offset the impact of substitution on employment, with about 9 million jobs created.[24] Additionally, productivity gains reinvested as spillover effects created between 3 and 12 million jobs, making a net gain (Exhibit 8). The numbers are representative of the pattern among the digital front-runners, though possibly proportionately lower in Scandinavia and higher in Benelux.

In some cases, the sectorial opportunity created by technology may be sufficient to compensate for lost employment. For example, Swedish companies adopting robotics in the early 1990s cut jobs at the rate of 1.7 percent a year, but after three to five years managed to grow sales by about 3 percent a year through reshoring and improved competitiveness. The sales increase led to a requirement to expand the workforce by 2 percent—more than was lost through robotics in the first place.[25] (For further examples, see the sidebars "Example: Reverse offshoring" and "Example: Productivity and employment.")

Exhibit 8

Technology has been a driver of job churn and job creation

Impact on employment of technology performing routine tasks, 1999-2010, millions of jobs



1 Based on upper and lower estimated bounds.
2 RRTC short for routine-replacing technology

Source: Gregory, Salomons, and Zierahn (2016); McKinsey analysis

24 Terry Gregory, Anna Salomons, and Ulrich Zierahn, "Racing with or against the machine? Evidence from Europe," discussion paper no. 16-053, Centre for European Economic Research (ZEW), July 2016, zew.de.

25 Steffen Kinkel, Christoph Zanker, and Angela Jäger, "The effects of robot use in European manufacturing companies on production off-shoring outside the EU," conference paper, June 2015.

Example: Reverse offshoring

Reshoring has been a notable trend in the digital front-runners since 2014.[1] Norwegian company I. P. Huse, which serves more than 90 percent of the global market for giant winches, in 2017 announced a full reshoring of its production facilities from Czech Republic, Poland, Russia, and Ukraine. Mechanization and robotics were cited as the main enablers. The motivation for using robots was not to replace labor, but to produce faster and with higher quality.

In the process of reshoring, I. P. Huse faced two challenges. First, it struggled to find employees capable of both welding and programming. Second, it was required to make design changes so that the product was suitable for automated production. Meeting those challenges required new employee skills.[2]

1 The European Reshoring Monitor (https://reshoring.eurofound.europa.eu/), a Eurofond initiative to track reshoring back to EU, has close to 40 mentions.

2 Tore Stensvold, "Ny trend: Norske bedrifter flytter hjem produksjonen fra lavkostland (New trend: Norwegian companies move production back home from low-cost countries)" TU, June 20, 2016, tu.no.

Example: Productivity and employment

In Denmark in 2012, the Odense Steel Shipyard, founded at the beginning of the 20th century, closed down as a result of the financial crisis and declining competitiveness. Its closure doubled unemployment in the municipality. A few years later, almost all of the displaced workers were back in employment at the same site. Vestas, a Danish producer of windmills, had opened a large production facility to serve rising demand for wind energy, which had become more affordable as the technology became more productive.

Technology creates a skills bias

Technology has contributed to job polarization and a skills bias, with high-skill and low-skill occupations seeing higher demand while middle-skill jobs have faded. The reason is that automation works best in explicit, codified tasks, characterized as routine.[26] Routine tasks are common in middle-wage jobs—for example, the mathematical calculations in bookkeeping or the repetitive physical operations on an assembly line.[27] There may also be an economic motive; it makes more economic sense to automate middle- or high-paid jobs than low-paid jobs.

Given that consumer spending, dominated by the middle class, has been a key driver of economic growth in developed economies, the drive to automate jobs performed by that section of the population raises questions for policy makers relating both to economic growth and the social fabric.

Computers and IT have created a requirement for more education in the workplace and raised the need for high-level skills by roughly 50 percent.[28] In a case study from 1980s, General Motors rebuilt an assembly plant with state-of-the-art robots and industrial automation.[29] This increased skill requirements, with 40 percent more of skilled workers saying that problem solving had become very important. The time required to train workers doubled.

The need to adapt to a new structure

The impact of automation in the workplace to date has not greatly affected overall levels of employment and has been a major source of productivity growth. But there is a twist: technology often changes the structure of employment. First, occupations change, obliging workers to adjust to new tasks. Also, technology is a substitute for people, reducing demand for workers. Meanwhile, new jobs are created as a result of companies being more competitive (often with a lag) or occupations are created in different sectors, when productivity gains are reinvested in the economy. This all requires occupational mobility. Finally, technology creates new skill requirements, and often higher-skill requirements, suggesting retraining is critical.

Those adjustments are not always simple and may lead to temporary friction. A recent study of 21 European countries finds that short-term unemployment may rise in the two years after technology advances, and abate after.[30] However, for automation to flourish in the workplace, and to foster inclusivity as quickly as possible, friction must be minimized and managed.

26 David Autor, "Why are there still so many jobs? The history and future of workplace automation," Journal of Economic Perspectives, volume 29, no. 3, Summer 2015, pp. 3–30.

27 Goos at al., "Explaining job polarization."

28 Michael J. Handel, "Dynamics of occupational change: Implications for the Occupational Requirements Survey," research paper prepared for the US Bureau of Labor Statistics, July 15, 2016, bls.gov.

29 Ruth Milkman and Cydney Pullman, "Technological change in an auto assembly plant: The impact on workers' tasks and skills," Work and Occupations, volume 18, no. 2, May 1991, pp. 123–147.

30 Horst Feldmann, "Technological unemployment in industrial countries," Journal of Evolutionary Economics, volume 23, no. 5, November 2013, pp. 1099–1226.

2. A more productive future for a resilient labor market

To date, technology has led to a positive relationship between productivity and employment at the economy level. To judge whether new digitally-enabled automation and AI technologies will produce a different result, we have produced a scenario analysis for possible outcomes based on the likely trajectory of automation and the links between diffusion, productivity and new job creation.

Our work leads to two key conclusions. The first is that, in the foreseeable future, automation will likely lead to a material productivity boost in the digital front-runner economies, with little risk of unemployment and even the possibility of a rise in employment. In other words, this time is not qualitatively different than the past, and speculation over a jobless future seems to be overblown. The second conclusion, however, is that the first conclusion holds only if the digital front-runners embrace technology diffusion, prepare for a transition to higher levels of reskilling, and use technology to create innovative products, services, and ways of doing business. The size of the challenge is significant, because a large proportion of existing tasks (and of jobs as bundles of those tasks) must be retooled and reskilled.

Assuming those conditions are met, our base case is that automation diffusion has the potential to add 1.2 percent of GDP per year by 2030 on average, with the same or better levels of employment. However, If the conditions are not met, or take time to be met, friction will create pressure on employment (and social pressure) in the short term, and possibly in the longer term as a result of recurrent poor matching. This underscores the importance of an effective transition based on cooperation between stakeholders to support change.

Weighing the arguments over technology's impact

The key debate around the next leap forward in technological disruption is whether it will lead to large-scale unemployment. We suggest probably not, but there are compelling arguments on both sides relating to the speed of roll out, its scope and the impact of shifting demographics.

The speed of technological innovation

- *Why different this time.* Technological and digital innovations are growing exponentially, reducing the time between disruptions from decades to years and putting pressure on the labor market's ability to absorb changes.
- *Why not.* There is a relevant distinction between innovation and enterprise diffusion. Faster innovation does not necessarily mean firms automate more quickly. Our research shows the most powerful driver of automation is whether a company has already invested in previous innovations, such as the cloud and big data. The result is that frontier firms tend to invest while others lag, slowing the overall pace of diffusion. The fact of divergent adoption between firms is backed by recent academic research.[31]
- *In practice,* the speed of diffusion is likely not to be faster than in the past, based on our survey of company plans to test and integrate AI technologies.[32] Assuming a constant rate of conversion across digital front-runner countries, we find diffusion rates will be similar to those for early mobile and other web-based technologies. The key sensitivity is the ROI attached to new automation investment, which is driven by the extent to which companies can acquire the necessary skills.

The scope of activities that can be automated

- *Why different.* Automation has in the past mainly replaced routine and physical activities, while in the future automation is expected to broaden in scope and take in cognitive tasks previously restricted to humans.
- *Why not.* In this report, we find that while automation is expected to become smarter in the next 15 years, there will still be a dominant set of activities for which AI-enabled automation is incapable, particularly

31 Diego Comin, "The evolution of technology diffusion and the Great Divergence," policy brief for 2014 Brookings Blum Roundtable, August 8, 2014, brookings.edu.

32 McKinsey Global Institute, Artificial intelligence.

where the task is to apply expertise, or relate to or manage people.

- *In practice,* automation has more potential than in the past, because it will start to undertake cognitive tasks on top of routine tasks. In the digital front-runner countries, we estimate that 44 percent of working time is automatable, which is higher than estimated for the personal-computer era and for early web technologies. As an example, we estimate that 41 percent of time spent working in financial services is automatable, while previous academic studies estimated the effect of ATM and PC technology to be much smaller than that.[33]

The sector scope

- *Why different.* Advances in automation have in the past focused on individual industries—for example robotics in manufacturing. The new wave is expected to have an impact on many (if not all) sectors, reducing alternatives for workers without the appropriate skills.
- *Why not.* Advances in ICT over the past decade have affected all industries.
- *In practice,* this is not different from the past, but the context may be. Automation now coincides with a stalling of productivity growth, suggesting that job creation may be more challenging than in the past.

Changing demographics

- *Why different.* Working-life expectancy has increased over the past century, implying lower job churn to help absorb new arrivals and a greater likelihood that workers will see their profession disrupted multiple times, creating challenges in continually adapting.
- *Why not.* Population growth has declined, reducing the supply of new workers. Hours worked have also declined following gains in productivity, so fewer jobs have been sacrificed.
- *In practice,* demographics are unlikely alone to have a significant impact. Demographics are also a much broader trend, in which automation may play a positive role.

Expansion of new job-category types

- *Why different.* In recent years, the creation of new job categories has slowed. In the United States, the rate is 0.4 percent per year, down from 0.6 percent 30 years ago.[34]
- *Why not.* More diverse technologies will likely lead to a wider range of jobs being created.
- *In practice,* according to our analysis, new job categories will emerge as AI infrastructure is rolled out, suggesting job-category growth will continue apace.

Automation's impact on existing tasks to be substituted

Technology substitutes jobs and creates new ones. The substitution effect up to now has centred on routine work flows, because early robots found it easy to replicate explicit actions that followed a strict set of rules. Calculating numbers is a simple example, while building a car is a more complex manifestation of the same thing. Tasks that demand judgment—for example, understanding people's motivations or setting priorities—are more challenging. In those areas, robots until recently were less able than human infants (Exhibit 9).[35]

One approach to circumventing the problem of computerizing tasks that do not follow a strict set of rules is environmental control.[36] For example, in manufacturing assembly lines, processes have been adapted to eliminate non-routine tasks. More recent

33 James E. Bessen, "How computer automation affects occupations: Technology, jobs, and skills," Boston University School of Law, Law and Economics Research Paper no. 15-49, October 3, 2016, available at https://ssrn.com.

34 Jeffrey Lin, "Technological adaptation, cities, and new work," Review of Economics and Statistics, volume 93, no. 2, May 2011, pp. 554–574.

35 The paradox that automation technologies can process astonishing volumes of data while lacking the judgment of a child is known as Polanyi's paradox. For example, IBM Watson is able to process 500 gigabytes of data (equivalent to the data in one million books) per second but is less sophisticated at understanding common sense and exhibiting judgment than preschool-age children.

36 David Autor, "Polanyi's paradox and the shape of employment growth," NBER Working Paper no. 20485, National Bureau of Economic Research, September 2014, nber.org.

Exhibit 9

Current technologies still underperform humans on some key capabilities

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

"smart" technologies, such as self-driving cars, also leverage this approach. Rather than following roads, they follow maps, which are compared with real-time audio-video data collected by sensors on the car. However, on unmapped roads, they cannot leverage this approach and are stuck.

Recent advances in artificial intelligence and machine learning take a different approach to the problem of hard-to-program tasks. While an engineer may struggle to "tell" the computer to do a task the engineer knows tacitly how to perform, he or she can program the machine to master the task autonomously by letting it study examples of that task being carried out successfully. Through a process of exposure, training, and reinforcement, machine learning is able to apply statistics and inductive reasoning to supply best-guess answers in cases where there are no strict rules to follow.[37]

Machine learning is a step change in machines' ability to mimic intelligent capabilities and an early sign that computers may be capable of turning information into something that looks like human knowledge. The implication is that more tasks previously reserved for humans may soon be automated.

The trend toward more advanced capabilities has been supported by improving economics. In the 15 years up to 2005, the price of robots fell by some 80 percent in the United States and major European countries.[38]

Some 44 percent of existing labor time in the digital front-runners is automatable, but less than a quarter of employees are at risk of redundancy

To estimate the impact of automation on work, we use a unique methodology of matching capabilities to tasks and then job occupations (for more on the academic work in this area, see sidebar "Academic literature focusing on automation"). Based on our research, we find that some 44 percent of working hours in the digital front-runners are automatable, compared with 46 percent in the Big 5 countries of Europe (Exhibit 10). Within the digital front-runners, there is little variation. Luxembourg has the lowest potential (38 percent of working hours), while Estonia has the highest potential (46 percent of working hours). Where there are differences, they come from sector composition and intra-sector differences such as variance in the occupation mix within a sector.

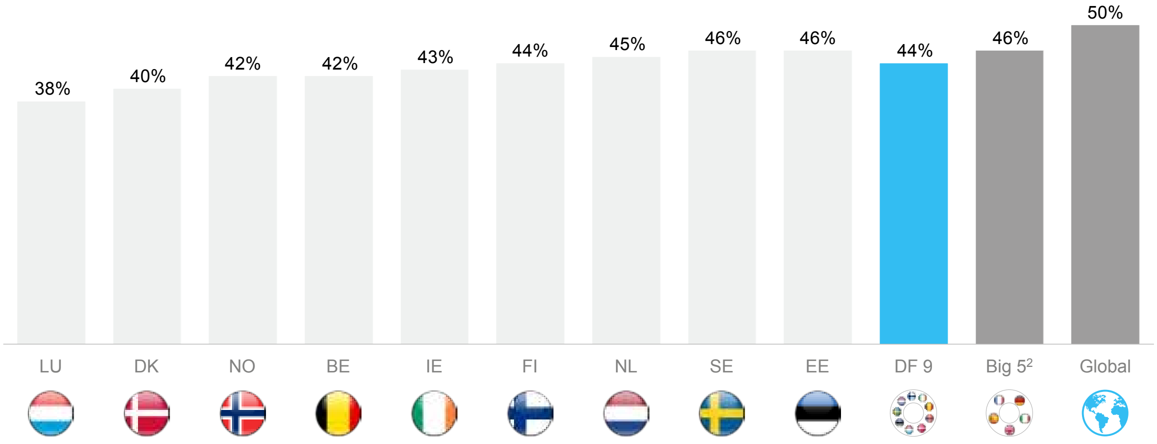
37 Ibid.

38 International Federation of Robotics, 2016, Chapter III

Exhibit 10

Automation potential of digital front-runners is slightly below the global average

Aggregated technical automation potential across countries,[1] % of working hours



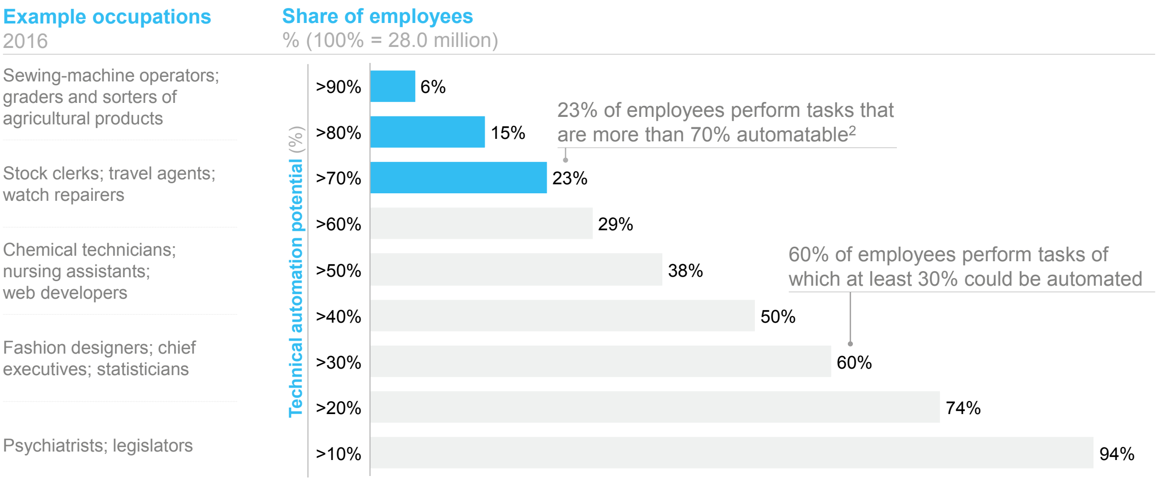
1 We define automation potential by the work activities that can be automated by adapting currently demonstrated technology.
2 France, Germany, Italy, Spain, and the United Kingdom.
Source: National Statistics, McKinsey Global Institute; McKinsey analysis

Across the digital front-runners, at least 10 percent of the work activities could be automated for 94 percent of the employees. However, only 23 percent of employees are in occupations that are more than 70 percent automatable, meaning they are susceptible to direct job losses (Exhibit 11). In other words, the majority of jobs will be reorganized, and employees' work activities will change. This pattern is visible across all of the digital front-runners.

Exhibit 11

Automation will affect almost all employees

Automation potential based on demonstrated technology in the 9 digital front-runner countries (cumulative)[1]



1 We define automation potential according to the work activities that can be automated by adapting currently demonstrated technology.
2 Share of jobs at risk of job loss by country: Luxembourg 18%; Denmark 19%; Norway 19%; Belgium 21%; Ireland 22%; Netherlands 23%; Finland 26%; Estonia 27%
Source: McKinsey Global Institute

Academic literature focusing on automation

In recent years, several valuable studies have investigated the impact of automation on the workplace. In 2013, Frey and Osborne published a paper aiming to quantify the number of jobs susceptible to automation based on known technology.[1] Their work used expert assessment to determine the automation potential for 70 occupations, which it extrapolated through use of machine learning.

In 2016, Arntz, Gregory, and Zierahn expanded on the work of Frey and Osborne, noting that particular work tasks, rather than full occupations, can be automated.[2] Based on the link between occupations and automation potential from Frey and Osborne, and the link between occupations and tasks from the OECD PIACC database, Arntz et. al. estimated the implied link between tasks and automation potential. While Frey and Osborne had concluded that 49 percent of jobs in digital front-runners had more than 70 percent of hours that could be automated, Arntz, Gregory and Zierahn cut that number to 8 percent. Their work also was based on expert assessment of automation potential.

In 2017, McKinsey Global Institute took a new, bottom-up approach, based on breaking down around 800 occupations into about 2,000 tasks and analyzing how each of the tasks drew on 18 capabilities (e.g., gross motor skills, sensory, emotional sensing).[39] The study analyzed technology performance against humans for each of the 18 capabilities. The approach supports the findings of this report. For more information about methodologies, see the appendix.

More formal mathematical models of automation and the labor market have also emerged. One example is the work of Acemoglu and Restrepo in 2016.[3] Based on a task-based framework, in which existing tasks can be automated and new, more complex task requiring labor can emerge, they find the economy tends to self-correct and restore initial levels of employment, labor share, and inequality between skill groups. However, all of these might be adversely affected during periods of labor transition.

1 Carl Benedikt Frey and Michael A. Osborne, The future of employment: How susceptible are jobs to computerisation?, Oxford Martin Programme on Technology and Employment, September 2013, oxfordmartin.ox.ac.uk.

2 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 no. 189, OECD Publishing, June 16, 2016, oecd-ilibrary.org.

3 Daron Acemoglu and Pascual Restrepo, “Robots and jobs: Evidence from US labor markets,” NBER Working Paper no. 23285, National Bureau of Economic Research, March 2017, nber.org.

39 A future that works: Automation, employment, and productivity, McKinsey Global Institute, January 2017, McKinsey.com.

Jobs with the highest potential for substitution will be the most routine, with less need for human interaction, problem solving and creativity. Breaking down the capabilities required to carry out each task, and bundles of tasks into jobs, the highest automation potential can be seen in transportation, hotels and restaurants, manufacturing, and trade (Exhibit 12). These sectors are also more likely to be affected by job-category loss, accounting for more than half the total in that group. At the other end of the spectrum, healthcare and professional services will be among the sectors least affected.

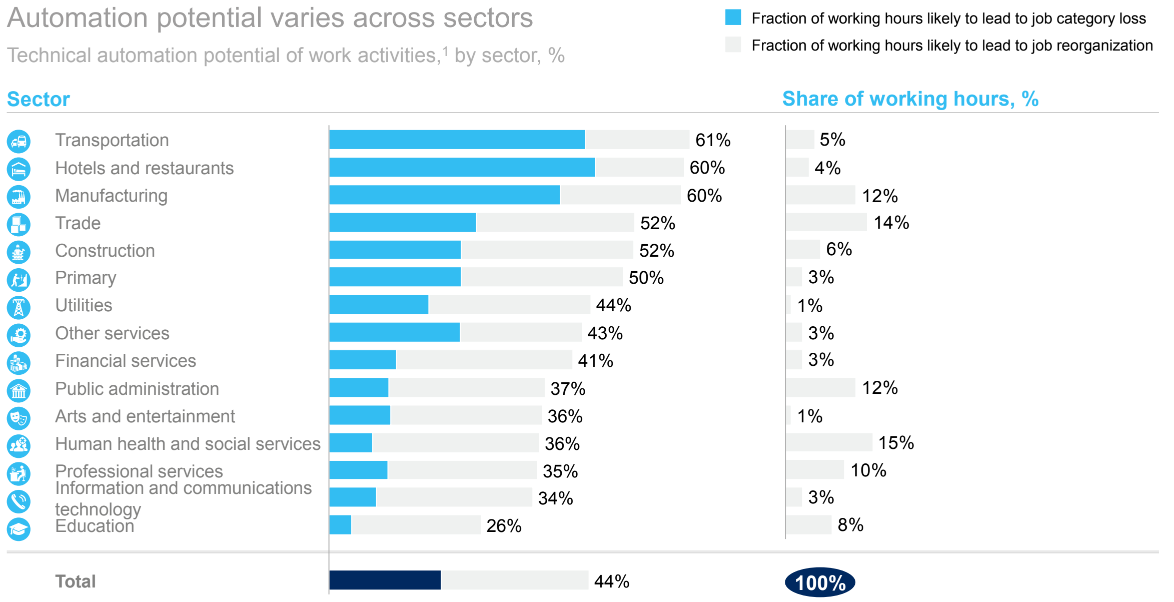
with a medium level of education (upper secondary and post-secondary). Those with the highest qualifications are less exposed to task changes, but are not immune to automation—with 30 percent of working hours being automatable.

Within those groups, there is a wide variation by sector, with, for example, healthcare workers much less likely to be replaced by machines than cleaners, who do more routine physical tasks. Overall, the results for the digital front-runners are in line with McKinsey Global Institute research.[40]

Exhibit 12

Automation potential varies across sectors

Technical automation potential of work activities,[1] by sector, %



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

Source: National statistics, McKinsey analysis

Impact of automation and AI will cross educational categories

In the past, technologies had the most impact on low-skill jobs, and productivity spillovers were mostly in sectors with demand for low skills, resulting in a polarization of job evolution. With new automation technologies, the substitution potential is spreading across education categories and will be equally felt by low- and medium-skill occupations. Some 56 percent of the working hours of the least-educated employees are at risk of automation, compared with 53 percent of those

AI diffusion patterns

We are only at the start of AI diffusion, and the current rate of adoption of AI technologies into business processes is relatively low. Just 17 percent of digital front-runner companies have started to integrate AI into business processes, and just 4 percent use the technology as an enterprise solution.[41]

In a recent McKinsey Global Institute report, we found the current pace of diffusion of AI varies by segment and between firms in the same segment, and that three key

40 Global results from McKinsey Global Institute, A future that works.

41 Based on a McKinsey survey of 200 executives in digital front-runner countries.

drivers guide appetite for adoption.[42] First, companies that already use technologies such as big data and cloud databases as part of their business logic are likely to be early adopters, both because the technologies support AI applications and because companies have learned new digital competencies and are more willing to invest in new technologies. The second driver is degree of clear articulation of a business case, and the third is the level of intent to use automation technologies as much for new innovation as for pure cost reduction.

Given the intrinsic difficulty in predicting future technology trends, we have taken a three-pronged approach to estimating how AI diffusion might spread among functions, firms, sectors and countries (see sidebar "Estimating the diffusion of automation"). All three lead to an average scenario where about 30 percent of digital front-runner companies will have integrated the full set of new automation technologies across every function of their business by 2030, roughly in line with the pace and level of adoption for earlier digital technologies.

There are significant uncertainties around these estimates. For example, diffusion speed will depend heavily on the expected return on investment of AI deployment. If returns double, for example, we expect some 40 percent more companies will adopt. In general, our research finds that a better ROI does not come from substituting more people with smart machines, but from innovation.

Estimating the diffusion of automation

We used three methods to estimate the diffusion pattern. The first is based on enterprise adoption rates for early digital technologies, which in fact are relatively slow. In digital front-runner countries, only 70 percent of companies have integrated 25-year-old basic web technologies (access, web services, social tech) at enterprise level. Mobile tech, which emerged around 15 years ago, is used across the enterprise in less than a third of digital front-runner companies.

We also looked at the current conversion rate per year between piloting AI and full-scale adoption. Assuming a constant conversion rate (an optimistic scenario, as early adopters are de facto faster than others), the aggregate diffusion curve implies that about 30 percent of companies will diffuse AI across the organization by 2030.

Finally, we leveraged the approach in McKinsey Global Institute's Future of Work, which examines economic curves based on the cost of tech compared with the cost of labor and the economic benefits of AI in terms of products and margins. The results are essentially the same as with the other two methods.

42 See Jacques Bughin, Brian McCarthy, and Michael Chui, "A survey of 3,000 executives reveals how businesses succeed with AI," Harvard Business Review, August 28, 2017, hbr.org.

The impact of automation may be balanced by significant new job creation

If technology substitutes jobs, a stylized fact of the past had been that technology has created a large impetus in new jobs. In fact, technology diffusion creates two types of employment: entirely new occupations and jobs tied to new product demand arising from increased productivity. Given that we expect the impact of automation to be broader than previously, higher productivity is likely. However, the constructive impact may be mitigated by economy-wide automation, which will reduce demand for labor across all sectors of the economy for the same GDP level.

In the United States between 1965 and 2000, new job categories made up 0.4 percent to 0.6 percent of annual employment growth, of which 50 to 70 percent was linked to technology.[43] As the role of automation and AI expands, those proportions are likely to rise. One recent study shows that every robot creates six tech jobs directly for every ten substituted.[44]

It is impossible to imagine all of the jobs that will be created through automation, just as it would have been impossible 50 years ago to imagine employment for chat room hosts, web developers, and cybersecurity experts. However, there are four basic occupational categories in which job creation directly linked to automation technology is likely to be concentrated:

- **Creators and suppliers of technology.** These occupations are directly involved in the creation of automation technology and infrastructure (e.g., engineers for the Internet of Things, robot designers, and software developers).
- **Enablers.** These are participants in ecosystems that help maximize the value added by technology. Key examples are data analysts and creators of business insights.
- **Utilizers.** This term refers to adopters of automation who find new applications for automation technologies (e.g., relating to big data and advanced analytics).
- **Other related jobs.** These occupations could include specialized legislators, legal experts, and accountants.

A typical employment split would be 25 percent creating and supplying technology, 40 percent enabling adoption, 25 percent utilizing and building on technology, and some 10 percent in other related occupations.

The total job-creation effect is also uncertain and is contingent on two assumptions. The first is that there is an increase in the pace of reskilling in the digital front-runners, which we estimate must increase by 1.3 percent per year.[45] Second, productivity gains must lead to new product and market opportunities. The good news observed in our recent research is that companies already adopting AI in enterprise processes are aiming to innovate into new products and services as much as reach higher levels of efficiency.[46]

Scenarios for the future of work in digital front-runner countries by 2030

We have plotted a number of scenarios based on the two critical uncertainties—the pace of technology diffusion and the pace of new-job creation—which will likely vary among digital front-runner countries depending on occupation mix and who owns the new automation supply chain (Exhibit 13). Ireland and Belgium are currently among significant net exporters of technology, while Denmark, Finland, and Norway are net importers.

43 Jeffrey Lin, "Technological adaptation, cities, and new work," Review of Economics and Statistics, volume 93, no. 2, May 2011, pp. 554–574; Aaron Smith and Janna Anderson, AI, robotics, and the future of jobs, Pew Research Center, August 2014, pewinternet.org.

44 Robert D. Atkinson and John Wu. "False alarmism: Technological disruption and the U.S. labor market, 1850–2015." Information Technology and Innovation Foundation, May 2017, itif.org.

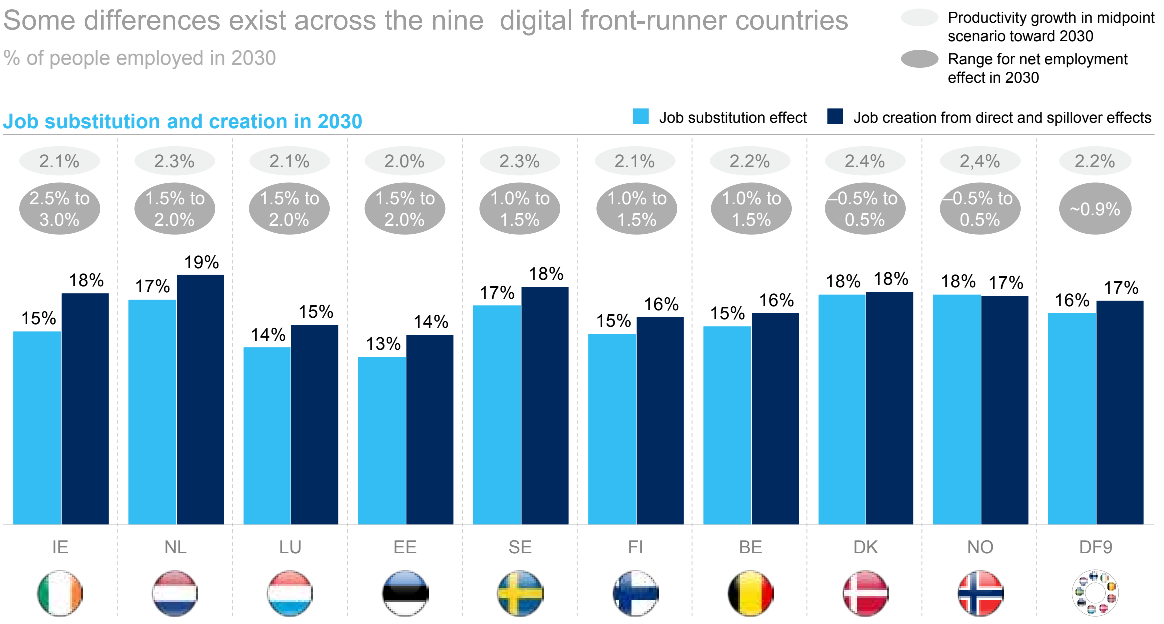
45 Historical required annual reskilling is calculated as the yearly fraction of forced occupation change due to decrease in labor demand for occupation a given occupation. The calculation is based on Danish micro-level analysis.

46 Jacques Bughin and Eric Hazan, "The new spring of artificial intelligence: A few early economies," Vox (McKinsey Global Institute blog), August 21, 2017, McKinsey.com.

Exhibit 13

Some differences exist across the nine digital front-runner countries

% of people employed in 2030

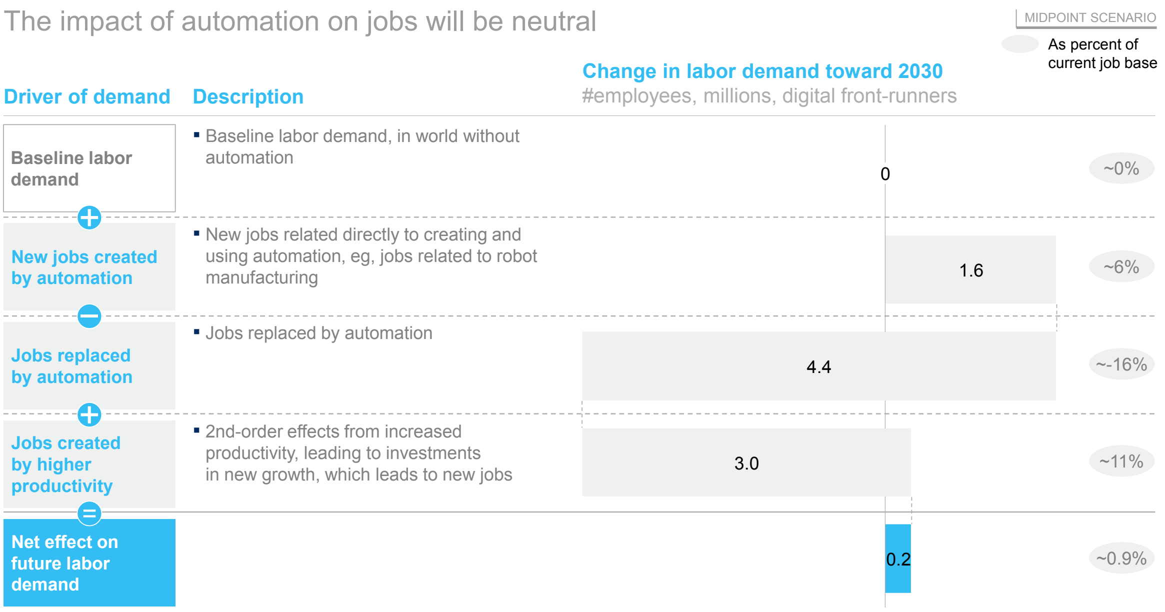


The base case

In the midpoint scenario, the picture is qualitatively unchanged from the present—that is stronger productivity growth than consensus forecasts alongside limited evidence of mounting unemployment, contingent on new skills being acquired (Exhibit 14). The net job impact will neutral or slightly positive, creating 200,000 more jobs, corresponding to 0.9 percent of the job base. The net job impact varies from neutral in Norway, to almost 3 percent in the case of Ireland.

Exhibit 14

The impact of automation on jobs will be neutral



Source: McKinsey analysis

GDP per capita growth in the digital front-runner countries will reach 1.9 percent annually by 2030— higher than recent consensus forecasts, despite recent productivity slowdowns (Exhibit 15). GDP per capita growth between the countries varies between 1.6 percent to 2.0 percent.

In the base case, the digital economy will account for 19 percent of digital front-runner employment by 2030, compared with 8 percent at present. Jobs directly connected to new automation technologies will account for at least 6 percent of the total.

Base case sensitivities

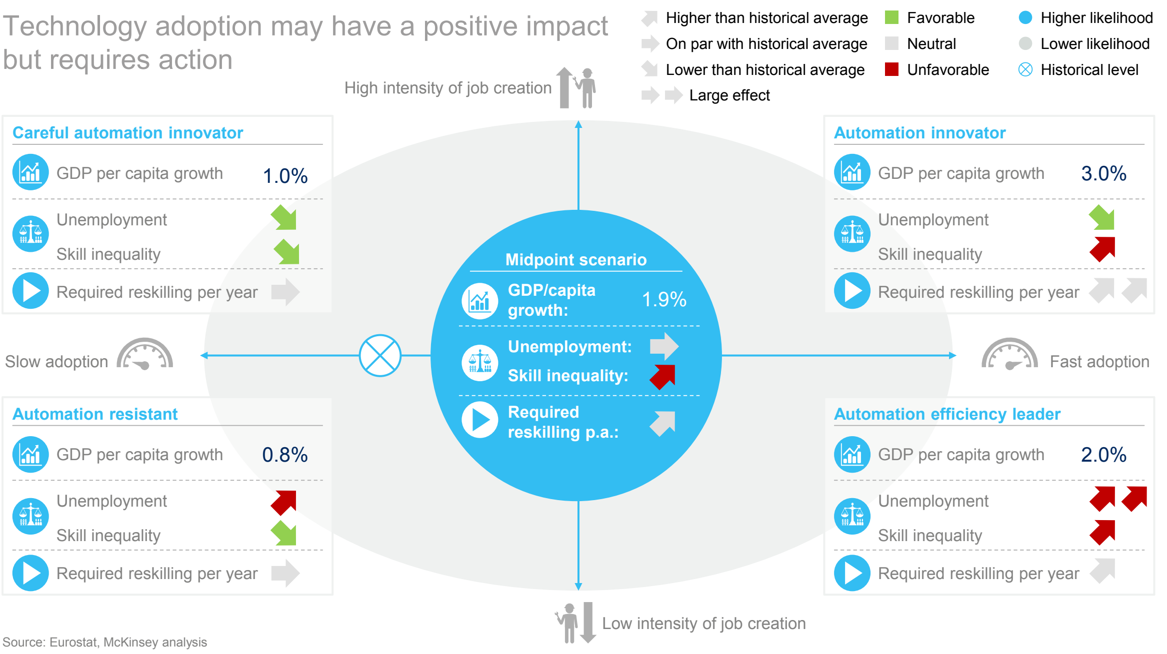
Two extreme scenarios confirm the importance of reskilling, fast adoption and innovation in sustaining productivity and employment. The first negative and the second positive.

In the extreme negative scenario ("automation resistant" in Exhibit 15), the pace of adoption is half as fast as expected, and there is half the job creation per job substituted (perhaps because AI is seen more as an efficiency tool than entrepreneurial driver). In that scenario, GDP/capita growth can be expected to decline by 50 percent from current levels. Employment will also be on a downward trajectory, declining at a rate of around 15,000 full-time equivalents a year. Growth and employment will need to come from sources other than automation.

The consequences of such a scenario are significant, with growth potentially no higher than during the recent financial crisis, and in line with the challenging outlook based on structural trends in the digital front-runner countries. This could lead to the increased public contempt for globalization and pressure for more protectionism. It may also create inter-generational issues, where younger citizens have less wealth than their parents. In the extreme case the scenario may even prove to be too optimistic. If other countries invest in automation and AI, digital front-runner companies would lose competitiveness, and growth in the resistant country would be around 0.4 percent as unemployment rises.

Exhibit 15

Technology adoption may have a positive impact but requires action



Source: Eurostat, McKinsey analysis

Under the most optimistic scenario ("automation innovator"), in which the pace of automation is faster-than-expected and reskilling is quick, GDP per capita growth will reach close to 3 percent, or nearly double the rate of the past 26 years. Further, it will generate almost 900,000 additional jobs compared to the midpoint scenario. The digital economy in that case will represent about 25 percent of total jobs, when including jobs indirectly created.

This scenario is extremely optimistic, as it is based on a presumption that companies do not incur major costs in transitioning to new business practices backed by automation and AI. Further, new skills will be critical to job creation, and today just one in nine adults receive on-the-job training in the digital front-runners, and with a wide variation (Belgium 7 percent, Denmark 30 percent).[47] The scenario underscores the attractiveness of fast adoption, but only if employees can be more broadly reskilled.

With these scenarios in mind, a public policy focused on impeding or restricting technology diffusion is likely to be less effective than one of embracing it. They also underscore the point that a core element of the future of work is to institutionalize new ways to upgrade skills.

47 Education and training monitor 2016; European Commission.


PATIENT PROFILE
PROGRAM DETAILS
NOTES
DOWNLOAD
MEDICAL
CARE
HEALTH

3. A new skill structure for the future

In our base case, the mix of skills and thus occupations linked to those skills in the workplace will materially shift over the coming years. The effect will be larger in numbers terms than the change in net employment, and there is a high chance of friction as workers are required to adapt to the new environment.

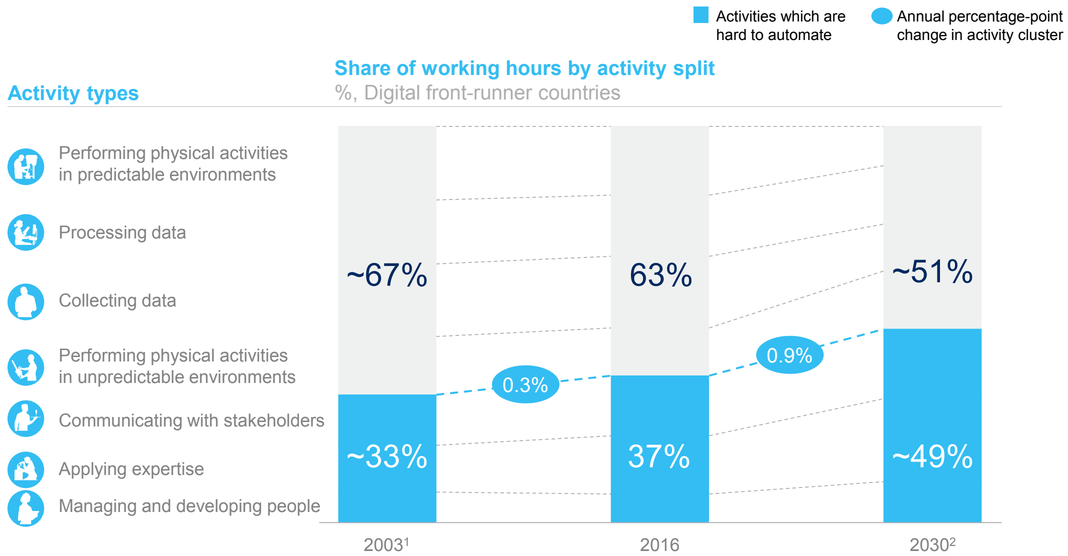
New set of skills, both technical and social, will dominate

The skills mix will change, as activities involving interacting, applying expertise and managing become more commonplace, and that dynamic is likely to accelerate. Our base case suggests demand for these types of activities will outstrip demand for other activity types by 2030, increasing to around 50 percent of working hours from 37 percent today (Exhibit 16). In the process of skill mix change two extremes will be that the proportion of routine-based jobs may decline by 7 points, while technically skilled jobs may be boosted by around 6 points. A large portion of those technical skills will be digitally-based, with the portion of digital jobs doubling in the next 15 years. In addition, jobs requiring managerial and communication skills will grow by 3 points apiece. Physical, but unpredictable skills, such as in healthcare, will also continue to see rising demand.

Global teams will boost demand for virtual-collaboration skills and additional technical complexity will increase the need for adaptive thinking.[48] Likewise, accelerating

Exhibit 16

Demand will shift toward activities requiring communication, expertise and managing people



1 Approximated from historical occupation mix in Netherlands and assuming same ratio of occupation mix change to change in activity mix within occupations as we forecast toward 2030.
2 Working hours are reallocated to activity types based on activity mix of new jobs created.

Technical skills of the future

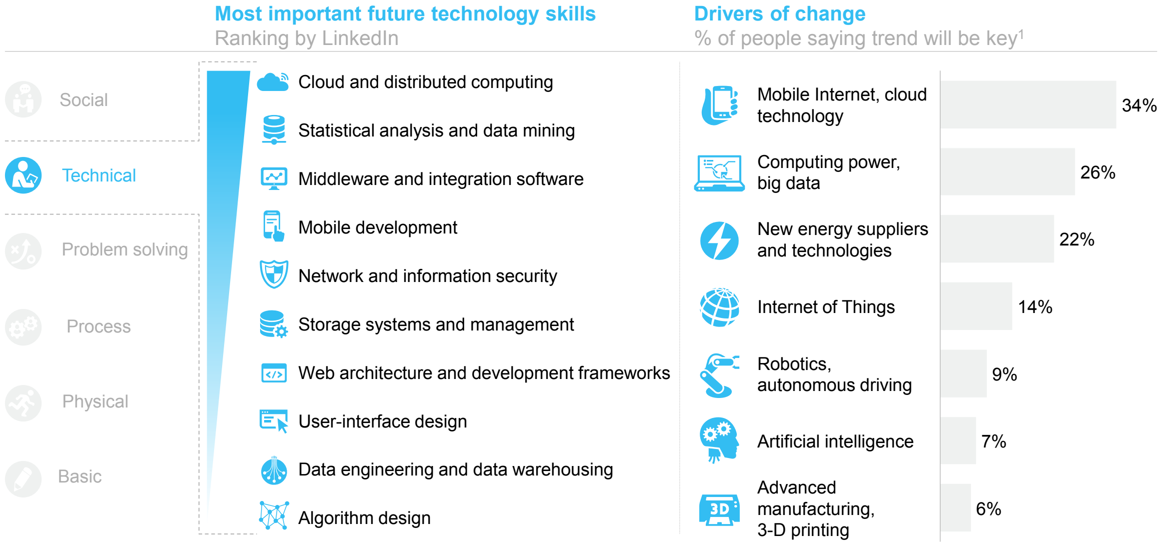
LinkedIn regularly updates data about the skills most in demand, based on activity on its website. Several of the skills have only recently found their way into today's job market. Most have a clear technical element—such as cloud and distributed computing, and network and information security (Exhibit 17). However, many require the ability to, for example, understand the customer and synthesize and communicate knowledge; such skills include user-interface design, data presentation, and SEO/SEM.[1]

1 SEO is search engine optimization; SEM is search engine marketing.

48 In fact, one study suggests that as AI becomes smarter, there will arise occupations that are related to AI but do not require a lot of technical skills. The researchers categorize the new jobs as Trainers, Explainers, and Sustainers. H. James Wilson, Paul R. Daugherty, and Nicola Morini-Bianzino, "The jobs that artificial intelligence will create," MIT Sloan Management Review, volume 58, no. 4, Summer 2017, sloanreview.mit.edu.

Exhibit 17

Major digital trends will drive skill requirements



1 Percentage of people responding that the trend will have a major impact toward 2025
Source: World Economic Forum, LinkedIn McKinsey

disruption will emphasize leadership and trans-disciplinary skills. Among technical skills, coding is a growth area, alongside expertise in specialties such as cloud technology, statistics, system integration, big data, and the Internet of Things (see sidebar "Technical skills of the future"). At the other end of the spectrum, demand for physical skills is likely to continue declining, which should mean more safety at work and fewer repetitive tasks (Exhibit 18). These trends are already in place, but the impact of automation will likely accelerate them.

Exhibit 18

Certain skills will be key in future high-demand occupations

✓ Skill particularly relevant ✗ Skill not relevant ✓ (grey) Skill somewhat relevant

Skills area	Examples of skills	Interfacing with stakeholders	Applying expertise	Managing and developing	Historic change in skill relevance,[2] 2003-2016, percentage points per year
Social	▪ Negotiation skills ▪ Social perceptiveness ▪ Virtual-collaboration skills	✓ (particularly relevant)	✓ (somewhat relevant)	✓ (particularly relevant)	↗ 0.2%
Technical	▪ Programming skills ▪ Technology-design skills ▪ Maintenance skills	✓ (somewhat relevant)	✓ (particularly relevant)	✓ (somewhat relevant)	↗ 0.2%
Problem solving	▪ Problem-solving skills ▪ Adaptive thinking ▪ Design mind-set	✓ (somewhat relevant)	✓ (particularly relevant)	✓ (somewhat relevant)	↗ 0.2%
Process	▪ Resource-management skills ▪ Transdisciplinary skills	✓ (somewhat relevant)	✓ (somewhat relevant)	✓ (particularly relevant)	→ 0.0%
Physical	▪ Fine motor skills ▪ Body coordination ▪ Physical strength	✗	✗	✗	↘ -0.6%
Basic	▪ Reading, writing, and basic mathematics skills ▪ Basic ICT literacy	✓ (somewhat relevant)	✓ (somewhat relevant)	✓ (somewhat relevant)	N/A[1]

1 Basic skills are relevant for all occupations and historical change have not been estimated for these skills.
2 Change in skill relevance is defined as the change in the share of occupations where skills is primary from 2003 to 2016.
Source: Word Economic Forum, McKinsey Global Institute

A likely accelerated shift in industry structure

It is difficult to assess how industry structure will evolve as it will depend on many dynamics. However, digitally-enabled automation and AI are likely to create more jobs in sectors including ICT, telecoms, healthcare and education services, while construction, travel-tourism, manufacturing and transportation will likely require fewer workers (Exhibit 19).

This likely shift in industry structure is already happening, so digital technologies may simply accelerate the evolution. While the majority of the occupations will remain in current industries, the capability requirement of those occupations will determine which are more likely to be replaced by robots. Further, those sectors might use AI primarily for efficiency purposes rather than job creation, and implementation is likely to be outsourced, limiting direct job creation, according to MGI research.[49] Currently, some 70 percent of transportation and manufacturing companies outsource AI implementation, compared with 50 percent in the broader economy.

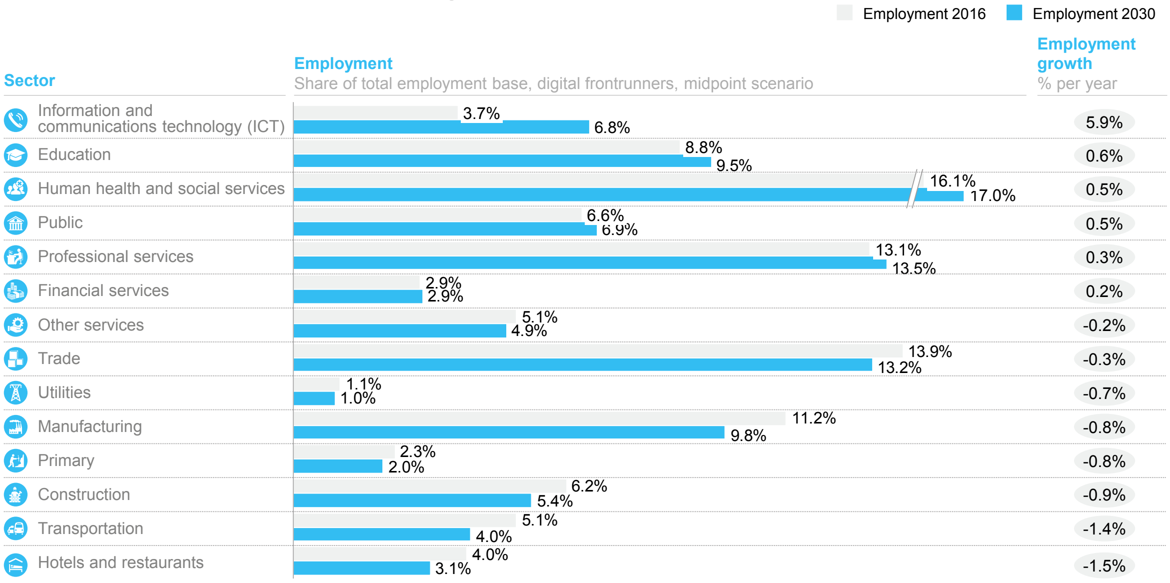
While a third of media, telecom, and financial-services companies see AI as an opportunity to expand their products and services, only 17 percent of transport companies and 10 percent of construction companies express the same view. One reason is that demand in those sectors is less elastic.[50]

This picture only expresses a trend, and may of course be reversed if proactive changes are made for more innovation and job creation, as has been seen in other contexts and industries. For example, despite a tendency for manufacturing sectors such as automotive to shrink their share of employment in developed countries, some Asian countries and Germany have adopted robotics in both upstream car manufacturing and downstream electronic services, and invested heavily in new products such the hybrid car. Swedish firms have on-shored some activities and created jobs locally. Where those kinds of initiatives have been taken, the share of manufacturing jobs in the economy has remained constant.

Exhibit 19

Automation will accelerate the change in sector structure

DIGITAL FRONTRUNNERS



Source: McKinsey analysis

49 McKinsey Global Institute, Artificial intelligence.

50 See David Autor's speech to the ECB for same observation. Results include two digital front-runner countries—the Netherlands and Denmark. David Autor and Anna Salomons, "Does productivity growth threaten employment?," paper presented at ECB Forum on Central Banking, Sintra, Portugal, June 27, 2017, ecbforum.eu.

Watch out for the transition

A successful transition to soft and technical skills is critical for a great future of work because the forthcoming changes will impact nearly all occupations in the digital front-runners. The amount of necessary reskilling varies significantly across jobs, but the most impacted are where mobility is traditionally low and retraining currently underpenetrated. More than three quarters of tasks performed by production workers are amenable to automation, but the figure is much lower for professionals. Occupation-group mobility also varies significantly (Exhibit 20). Senior management faces low automation potential and is highly mobile, while transport workers are generally in the opposite position.[51]

Some workers in the most affected occupation groups are relatively well equipped to transition into occupations less affected by automation, while others are not, and there is a wide variation in the type and degree of reskilling required (Exhibit 21).[52] Office and administration workers may have more relevant skills for future needs than those working in farming, fishing, and forestry.

However, employees may have tangential skill sets that are useful: food-preparation workers may lack IT skills but have strong social skills, enabling a smooth transition to other service industries.

On top of occupation-mobility, training rates are rather different by occupation. In the 28 countries of the European Union, just 4.3 percent of workers in low occupation jobs had entered formal enterprise training by 2015, compared with 10 percent of the entire working population, according to the European commission.

How the transition is managed will be crucial. Variables on reskilling include the time it takes to adjust and the share of employees who fully upgrade, which can have a material impact on net job creation. If, for example, there is 3-year gap between job substitution and job creation and if only 80 percent of the additional reskilling need is successfully fulfilled, then the predicted 240,000 extra jobs created by technology by 2030 in the digital front-runners will turn into a 670,000 shortfall.[53] If just 10 percent of necessary new skills are not generated, an additional 300,000 jobs are at risk.

51 Here mobility is defined as the fraction of people shifting occupation from 2000 to 2015 relative to total employment in 2015.

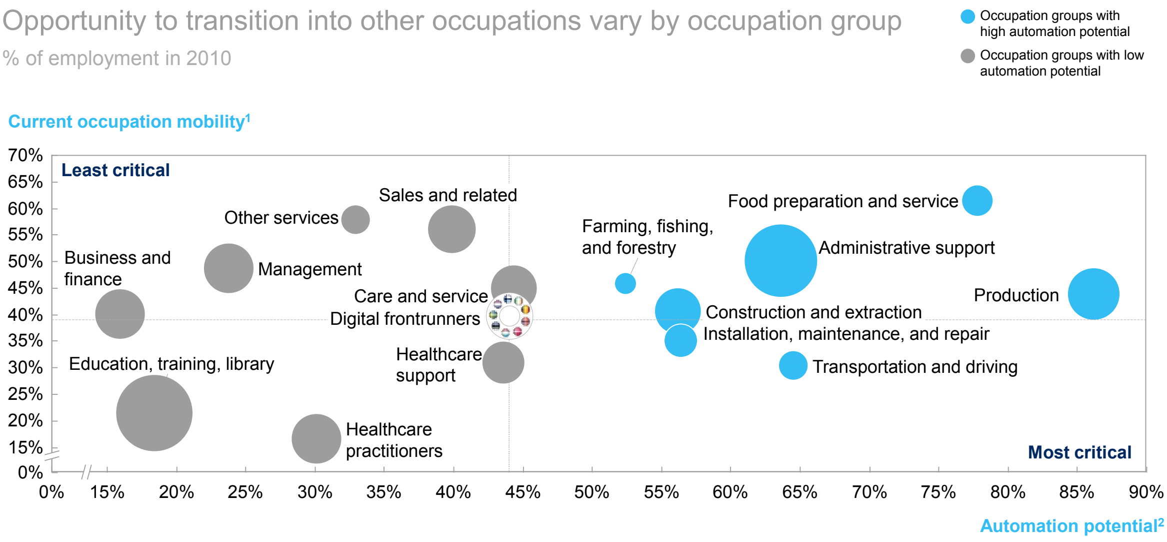
52 "No skills gap" is defined as skill level on par with that of employees in occupation groups less affected by automation. Skill levels assessed using the OECD PIACC database.

53 McKinsey analysis and Automation, labor productivity and employment: A cross country comparison., Kromann, Lene, Jan Rose Skaksen, and Anders Sørensen, 2011

Exhibit 20

Opportunity to transition into other occupations vary by occupation group

% of employment in 2010



1 Defined as people leaving the sector to another sector relative to employment in sector in 2010.
2 Percentage of total working hours that can be automated, 2016.
Source: Eurostat, Statistics Denmark, McKinsey analysis

Exhibit 21

Most-affected occupations have various skill requirements to transition to new jobs

Digital front-runner countries

Skills gap:[1] Significant, Large, Medium, Small, No skills gap

Occupation groups most affected by automation	Employees %	Examples	Skill evaluation, by skills area[2]: Basic	Technical	Problem solving	Process	Social
Office and administrative support	13%	▪ Financial clerks ▪ Office support workers	No skills gap	No skills gap	No skills gap	No skills gap	Medium
Food preparation	4%	▪ Serving workers ▪ Food-preparation workers	Medium	Large	Small	Small	No skills gap
Transportation	7%	▪ Vehicle operators	Small	Medium	Small	Large	Large
Construction and extraction	5%	▪ Construction trades workers	Medium	Medium	Medium	Medium	Large
Physical skills	7%	▪ Metal workers ▪ Plant operators	Medium	Large	Medium	Large	Medium
Installation and repair	3%	▪ Vehicle mechanics	Medium	Significant	Medium	Large	Large
Farming, fishing, and forestry	2%	▪ Agricultural workers	Large	Large	Medium	Large	Medium

1 Skills gap is defined as difference in skill level between occupations with likely job loss and hard-to-automate occupations.
2 Skill evaluation based on OECD PIACC database. Gap defined as deviation from average employee.
Source: OECD PIACC database, McKinsey MGI model, McKinsey analysis

4. A five-point agenda can support the future of work

From a stakeholder perspective, a failure to embrace technological change would be a self-defeating strategy, limiting growth, putting downward pressure on wages and potentially allowing competitors to steal a march. The key in formulating a strategy is instead to work to ensure new jobs are created quickly and that the transition is well managed.

Policy makers are already aware of the need to build a more advanced digital agenda, and countries including Belgium, Denmark and the Netherlands have set up dedicated public entities. However, while good, this is not sufficient: The challenge is also to plot a transition path that creates the right evolution for a strong future of work.

We propose five key strategies that should be pursued in parallel, which we believe will create the right local conditions to invest, secure appropriate skills and create a social fabric to facilitate employment transition. Finally, digital front-runner countries should seek to shape the global agenda on automation and AI technologies, in areas such as open data, privacy and security:

1. **Work to maintain digital front-runner digital leadership status.** While typically ahead of peers on broadband infrastructure, front-runners must continue to secure leadership in next generation of digital infrastructure and ensure that platforms are interoperable creating scale for new technology to flourish.
2. **Support local AI and automation ecosystems.** Encourage experimentation, nurture talent, and foster public R&D to nurture the creation of jobs in the local economy.
3. **Educate and train for the future of work.** Reorient education systems to improve science, technology, engineering and maths (STEM), leverage automation technologies in education, emphasize lifelong learning, and support on-the-job training.
4. **Support worker transition.** Develop social models and policy to smooth job transition.
5. **Shape the global policy framework.** Digital front-runners should participate in shaping global policy for the use of new technologies, including a code of ethics for AI and robots, and parameters around open data, privacy and cybersecurityFocus on future policy, addressing issues including cybersecurity.

1. Work to maintain digital front-runner digital leadership status

The faster the digital front-runners adopt AI, the quicker they will see productivity gains. That matters because, as small, open economies, they must be able to grow in order to maintain their competitiveness. One of the risks of slow adoption is that they will fall behind competitors and miss opportunities in export markets. Digital front runners are already losing momentum in this respect; Germany was the first European country to develop an infrastructure view to support 'Industry 4.0'.

Priority 1: Initiate and invest in infrastructure

As for the first generation of web infrastructure and broadband, governments can encourage adoption by investing in enabling infrastructure and platforms, such as the Internet of Things or more efficient standards, such as 5G, that will capable of supporting heavy data applications such as driverless cars, as well as promoting open standards and the sharing of data. This strategy should include adoption of common standards, ensuring equal access to data or more basic investment in shared physical or digital infrastructure. In Finland, public funding from Tekes, the national funding agency, has spearheaded an open 5G test network. [54] In turn, this has stimulated collaboration, as seen between Nokia and Intel.[55]

Priority 2: Remove barriers to adoption

The main drivers of adoption of automation and digital technology are competition and an adequate regulatory framework.[56] Competition is typically boosted when start-ups challenge incumbents, and governments may boost competition if they offer incentives and supportive legal environments for startups. Regulation typically fosters adoption where it supports new technology uses and applications, or secures inter-operability of technology solutions.

54 Finpro, "Finland introduces the world's most advanced 5G test network," news release, February 23, 2016, finpro.fi.

55 "Intel and Nokia to open acceleration lab for 5G innovations in Finland," Invest in Finland (Finpro web page), February 28, 2017, investinfinland.fi

56 McKinsey Global Institute, Artificial intelligence.

Digital frontrunners countries are already acting. In one early move, Estonia drafted legislation for testing of self-driving cars and delivery robots, the lessons of which will be used to inform future laws.[57] Sweden is one of the most prolific technology hubs in the world on a per capita basis, and has seen the creation of new digital native and "unicorn" companies, often as a result of strong public/private partnerships.[58]

An important element is taxation, and there has been some suggestion of taxing robots.[59] In general, taxes should target corporate profits based on actual results. Taxing robots upfront would likely impede the incentive to invest in automation, thereby slowing adoption.

2. Support local AI and automation ecosystems

The most digitally advanced countries often benefit from a strong digital ecosystem and a large digital sector that can create jobs locally and globally. These ecosystems are built on agglomeration and network effects, with a critical mass of researchers, developers, financiers, and customers who can create a fertile network in which innovation and entrepreneurialism can thrive. Our review finds that in 2016, the United States absorbed around 66 percent of external investment in AI (venture capital, private equity, and M&A activity), with almost two-thirds of that going to ecosystems in Boston, New York, and the San Francisco Bay Area and Silicon Valley.[60] China has ecosystems in Beijing and Shenzhen. London is the AI leader in Europe.

Priority 3: Lead by example in the public sector

One straightforward AI application in the local eco-system would be to put in place AI-based e-government initiatives. For example, e-Estonia carries a range of public services online, including access to healthcare data through KSI, an Estonian-developed blockchain technology.

Priority 4: Encourage local experiments and local talents

Policy makers can foster technological ecosystems by encouraging experimentation and supporting talent. The United Kingdom, for example, has established the Tech Nation Visa Scheme, which awards up to 200 visas annually, without work-sponsorship requirements, for applicants with exceptional talent or promise in the digital space. In Sweden, the municipality-owned renovation agency Renova has teamed up with Volvo in pioneering testing of autonomous garbage trucks, intending to increase safety and optimize fuel consumption.[61]

Priority 5: Foster public R&D

Funding for science programs is important, whether through grants to universities, creation of government laboratories, or joint research initiatives with the private sector. The U.S. government invested more than $1 billion in unclassified AI R&D in 2015.[62] The South Korean government has said it is investing 1 trillion won ($900 million) to build a public-private AI research center jointly with leading Korean conglomerates.[63] China's National Development and Research Commission has started a national engineering laboratory, led by Baidu, to conduct research into deep learning.[64]

3. Educate and train for the future of work

Our analysis demonstrates the need of a major transition from routine-based skills to new social and creative skills. To address this transition, policy makers should

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57 "Estonia allows self-driving cars on the roads," Estonian World, March 2, 2017, estonianworld.com; Chris Velazco, "Estonia is first in the EU to let cute delivery bots on sidewalks," Engadget, June 15, 2017, engadget.com.

58 A "unicorn" is a digital start-up now valued at more than $1 billion.

59 Kevin J Delaney, "The robot that takes your job should pay taxes, says Bill Gates", Quartz, February 2017,, https://qz.com/911968/bill-gates-the-robot-that-takes-your-job-should-pay-taxes/

60 McKinsey Global Institute, Artificial intelligence.

61 Volvo, "Volvo pioneers autonomous, self-driving refuse truck in the urban environment," news release, May 17, 2017, volvogroup.com.

62 National Science and Technology Council, "Preparing for the future of artificial intelligence," Executive Office of the President, October 2016.

63 Mark Zastrow, "South Korea trumpets $860-million AI fund after AlphaGo 'shock,'" Nature, March 18, 2016.

64 Weining Hu, "How China is becoming a world leader in artificial intelligence," China Briefing blog, March 14, 2017.

work with education providers to improve basic skills through the school system and put 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, policy makers could intervene to help workers develop skills best suited for the automation age. As a major employer, the government should not only act as a facilitator, but as a promoter of new learning solutions through automation, for example through virtual education.

Priority 6: Reorient curricula toward the future of work

The education system must be redesigned to provide opportunities to learn new technical and soft skills in STEM subjects (see sidebar "Future of the primary school"). It may be necessary to emphasize the creative and experimental aspects of some sciences. Learning to learn is important in anticipation of persistent shifts in demand, as is stimulating entrepreneurship.

Priority 7: Promote automation technologies for new forms of learning

Digital technologies can support educational capacity, control costs, and boost quality. In one example, virtual classrooms can increase the accessibility and scalability of lectures and allow for more personalized and flexible education models. Kennisnet in the Netherlands has provided virtual education since 2005, and the Koulu 360 initiative in Finland aims to develop the country's first virtual school.[65] Around the world, virtual education for free, such as massive open online courses (MOOCs), has boomed since 2011, led by companies including Coursera, edX, and Udacity.

Priority 8: Emphasize lifelong learning and higher education

Technical knowledge tends to become obsolete quickly, so there should be more emphasis on lifelong learning, perhaps leveraging short-cycle education. Of the digital front-runners, Estonia and Finland still lack short-cycle tertiary education, and elsewhere it makes up a small part of the tertiary system.[66] By comparison, people with

Future of the primary school

Coding is likely to be in high demand, and several initiatives are under way. England is the first European country to mandate coding for children aged five and up. The curriculum teaches students about logic, algorithms, debugging, and Internet safety. Estonia began including programming in its curriculum in 2012 for schoolchildren as young as six through its ProgeTiger program.

Finland has introduced computer programming as part of the core syllabus for primary school, with the aim of expanding accessibility. Computer logic is integrated into other courses—for example, learning about loops in art classes or through active engagement with other students in physical education. The government has worked with private providers to build the curriculum and support teachers.[1]

Sweden will teach programing in primary school from 2018 and will include lessons on source criticism, distinguishing between reliable and unreliable sources.[2]

1 Emily DeRuy, "In Finland, kids learn computer science without computers," The Atlantic, February 24, 2017, theatlantic.com.

2 Lee Roden, "Swedish kids to learn computer coding and how to spot fake news in primary school," The Local, March 13, 2017, thelocal.se.

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65 Glenn Russell, "Online and virtual schooling in Europe," European Journal of Open, Distance and E-Learning, April 3, 2006, eurodl.org; Ulla, "Meet the people behind Finland's first virtual school," Medium, August 3, 2017, medium.com.

66 "Tertiary education statistics," Eurostat, ec.europa.eu, data extracted August, 2017.

employment experience in the United States often return to education to take master's degrees.

Priority 9: Provide for on-the-job training and digital apprenticeships

There is an opportunity to support companies' programs for more frequent and diverse on-the-job training, as well as to build focused reskilling programs (see sidebar "National reskilling programs"). One approach would be to establish activity accounts for lifetime learning and job retraining, with the government, companies, or individuals contributing. Similar to a retirement account, money could be invested tax free, as is currently being set up in France.

Priority 11: Assess flexibility in adjusting hours worked per week

In the past, automation has led to a decline in hours worked. Policy makers should assess the trade-off between shorter hours and salary gains. Part of any reduction in work time could be assigned to on-the-job training; an approach being trialed in France. It is not clear whether shorter work weeks lead to more employment; policy makers must investigate further.

5. Shape the global policy framework

Priority 12: Support the development of AI ecosystems

Digital ecosystems play an intrinsic and essential role in capturing job creation. However, AI and automation will also lead to other challenges—for example, ensuring more global cybersecurity, respecting privacy, and establishing codes of ethics. Policy makers should pay proper attention to these areas as necessary conditions of preparing for the future or work.

Europe is already starting to gear up; the European Commission is exploring the possibility of developing an AI-on-demand platform and introducing EU-wide civil law rules on robotics and artificial intelligence. Policy makers should pursue this further to ensure Europe leads on developing scalable solutions for job creation. Other initiatives may include a forum for knowledge-sharing, common standards and prioritization of critical

National reskilling programs

Skills Norway, the Norwegian agency for lifelong learning, offers individually adapted training in literacy, numeracy, ICT, and oral communication for adults. In addition, the agency plays a central role in developing the skills of immigrants.

In Luxembourg, INFCP is the national institute for promoting vocational training. It helps employers and employees structure skill paths, provides an overview of private programs that offer skill upgrades, and partly funds skill upgrades through tax schemes.

SkillsFuture in Singapore grants about two million citizens around $345 toward training courses provided by 500 approved institutions. The program has additional subsidies for people over the age of 40 and offers individual career and skill ladders targeting citizens in low-wage occupations, developed in collaboration with unions and employers.

4. Support worker transition

Priority 10: Experiment with social models to support worker transition

As automation accelerates the shift to a freelance economy, more people will lose employment benefits such as pensions, maternity pay, and sick pay.
Policy makers must erect a safety net to ensure new employment forms can evolve in a socially responsible manner. More workers will likely need to transition into other jobs. Adequate social support will support them in this transition. Experimentation will be important to find out what works. Finland is experimenting with a universal basic income, providing some citizens with €560 a month, and the Netherlands has a similar program.

infrastructure. EU represents an important market for firms in digital front-runner countries and it is an opportunity for them to work together in order to create the most open and permissive environment

Our agenda for change is relevant to governments, industry and the wider community. All stakeholders should work to identify the most effective set of actions for a successful transition. For example, employee representatives must understand the importance of more on-the-job training, which must be supported by employers through a focus on life-long learning.

Automation and other new digital technologies are here to stay; it is now crucial that all stakeholders work to formulate a cooperative strategy to facilitate the transition to the future of work. We are eager to play a proactive role in the debate and development of action plans for the digital front-runners.

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The report draws on a body of existing and ongoing research at McKinsey Global Institute, including the institute's analytical framework and methodology to estimate automation potential and an enterprise survey of firms integrating new technologies in their business processes.[67] We have benefited greatly from discussions with James Manyika, Eric Hazan, Susan Lund and Michael Chui.

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Disclaimer

This publication is not intended to be used as the basis for trading in the shares of any company or for undertaking any other complex or significant financial transaction without consulting with appropriate professional advisers.

67 Please see e.g., McKinsey Global Institute. Artificial intelligence: The next digital frontier? Discussion paper, June 2017, McKinsey Global Institute. A future that works: Automation, employment, and productivity. January 2017.

Appendix: Methodology

Overall research approach

Our view of how automation technologies will affect productivity, employment and skills relies on a simulation model of labor demand and supply by education skills and by occupation for each of the nine digital front-runner countries. The model is calibrated to current labor dynamics as a base case, and to how technologies have affected employment in the recent past, adjusted for early evidence of how automation and AI technologies may make a difference.

Structure of the model

We build a base case without automation, where labor supply is based on population forecasts and participation rates by gender and age. Labor demand development is based on current labor employment, plus extra required to meet the consensus growth forecast, reduced by the portion of productivity growth induced by current set of technologies. Total employment is the minimum of labor supply and labor demand. In the base case, we also posit that the returns from previous waves of digital technologies will peak by 2020. Hence, the simulation results are the difference between the base case and an economy whose products and labor markets are affected by the adoption and diffusion of automation technologies.

The model treats wages as exogenous, and it is not intended to be a complete full-equilibrium model of an economy. Such models are beyond the scope of the current study. General equilibriums are extremely valuable resources but are also somewhat theoretical in their approach.[68] They suggest that in the long term, wages will be depressed by excess labor and automation substitution based on the relative price of robots, putting a floor on the risk of major labor work depletion. In practice in our model, we have assumed that wages follow the trend of the past. For the base case, we simply continue the recent pace of wage evolution, with labor productivity growth, for each country. For the automation case, we assume wages will continue to grow at the same pace as in the base case. This implies that about half of productivity gains are passed into wages, and 50 percent in new employment.

We also consider some key interdependencies. For example, rising unemployment reduces domestic demand, and gains in productivity through automation lead to increasing employability.

Calibration of the model

We have resorted to various data sources to obtain an informed view on the market dynamics linked to technologies and automation. We performed an exhaustive review of the academic literature on the topic (100 major research papers) to understand the various channels of employment dynamics linked to technology diffusion. Diffusion of previous technologies is assumed to peak by 2020, so mechanics of employment linked to previous technologies are neutral after.

Concerning the dynamics linked to new automation technologies, we have used an approach consistent with research performed by McKinsey Global Institute to estimate how a set of automation and artificial-intelligence technologies will be technically able to match human task performance in the context of task and job distribution in the digital front-runner countries. In practice, we directly match any job task from the US-based O*Net and OECD-based PIACC classification to a set of 18 skills and capabilities, and we forecast bottom up how those capabilities can be technically and economically performed by automation technologies. The advantage of the approach is that it does not regard jobs in aggregate, but as a bundle of tasks, and we align technological-capability evolution to human time spent and working hours, to estimate share of time at risk of obsolescence.

We also rely on a major survey conducted for parallel research on the likely patterns of adoption of artificial intelligence and their related drivers. This was conducted by an external market-research firm in the spring of 2017, with some results available in a separate MGI report.[69] The data set comprises more than 2,000 companies and is stratified to reflect both the size and sectoral distribution of firms. The survey shows how adoption patterns are dependent on factors such as expected return on technology deployment, market competition,

68 For example, David Hémous and Morten Olsen, "The rise of the machines: Automation, horizontal innovation and income inequality," working paper, December 4, 2014, available at blog.iese.edu/olsen/.

69 McKinsey Global Institute, Artificial intelligence.

and new skill and organizational requirements. Those adoption patterns are based on European data and, when enough data are available, specifically for data collected from Dutch and Swedish companies.

Estimation of current technical automation potential

There are many methods to estimate the technical potential of automation. One seminal work was by Oxford University researchers Frey and Osborne.[70] Their method is based on a two-step approach. First, they extract a relatively small sample (10 percent sample size, representing 70 occupations) of a list of 700 occupations in the O*Net database of US occupations. For the probability of substitution, they use as a proxy the share of an AI expert panel who consider those occupations to be automatable. Using this sample, they then run machine-learning techniques to estimate the probability of automation for the remaining 90 percent of occupations. Using 70 percent probability as a threshold for job loss, the methodology suggests that up to 50 percent of U.S. jobs could be substituted.

A major caution related to this method is that the analysis is done at the job level, while we argue the real risk of automation happens at the task level, and jobs are themselves bundles of tasks. If tasks to be automated are distributed randomly across jobs, then a larger portion of jobs can be affected, but the share of time to be substituted will be lower. This is the recent insight emerging from the work by Arntz and colleagues for the OECD,[71] demonstrating that less than 10 percent of jobs will see 90 percent of tasks fully automated. Arntz's work uses a probabilistic method, and not direct matching of tasks that can be automated per occupation. We develop the method through direct matching of the automation potential for each of the 2,000 defined tasks, based on the set of the automation technologies covered in this report.

Pace of automation diffusion

Adoption of automation technology depends on multiple factors, including technical feasibility, solution development, economic feasibility, and end-user adoption. All of those factors guide the diffusion patterns across time, as described in a McKinsey Global Institute report on the future of work.[72]

To estimate the diffusion of automation technologies, we have relied on several benchmarks on the diffusion of technology. We have calibrated the results with the diffusion of past technologies in enterprises. For instance, after 25 years, two-thirds of companies have invested in all of the first generation of web technologies (web services, intra- and extranet, communication technologies). In estimating the adoption pace, we also take into account several considerations informed by the latest survey on technology adoption from McKinsey Global Institute:[73]

Differences among companies. Firms have different cost structures, meaning that economic feasibility will occur faster for some firms and later for others, even within the same sector. Likewise, not all firms experience the same level of organizational and skills barriers to diffuse those technologies in their enterprise. Hence, our survey implies that, by 2030, for every company with integrated automation technology across the enterprise, another one will not have adopted at all or will have adopted only for some functional objectives.

Differences in competitive environments. Diffusion depends on intensity of competition, especially if gains from automation lead to improved competitiveness, which in turn can catalyze shifts in market share. In general, this has a significant effect on timing of adoption. Based on expectations for competition intensity, we find that a doubling of competition intensity increases diffusion speed by 40 percent.

70 Carl Benedikt Frey and Michael A. Osborne, The future of employment: How susceptible are jobs to computerisation?, Oxford Martin Programme on Technology and Employment, September 2013, oxfordmartin.ox.ac.uk.

71 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 no. 189, OECD Publishing, June 16, 2016, oecd-ilibrary.org.

72 McKinsey Global Institute, A future that works.

73 McKinsey Global Institute, Artificial intelligence.

Differences among sectors. Diffusion will differ according to sector. Companies in manufacturing foresee relatively more efficiency gains from automation than from new products and services; the opposite is the case for media and consumer high-tech companies. Based on our survey results, sectors such as ICT and manufacturing will adopt faster, while the public sector and construction will have a slower pace of adoption.

Scenarios for the impact of automation

The simulated results are based on the following four steps.

First, the adoption at firm level is guided by the expected gains from automation and competition intensity. Adoption leads to two types of gains from diffusion: efficiency gains from jobs being substituted by new smart machines, and effectiveness gains from new market opportunities that arise from automation. In our midpoint scenario, the gains appear large, with roughly 50 percent from substitution gains and 50 percent from output expansion (from new ICT value-chain developments, new products and services within the sectors adopting, and new-product demand spillovers in other sectors, due to reinvestment of productivity gains in the entire economy).

Second, we assume that the degree to which the substitution of tasks leads to job substitution depends on the portion of jobs with a high share of tasks that can be automated. Occupations for which a high share of tasks can be automated will experience relatively quick job losses. In the case of occupations with a smaller share of tasks that can be automated, the jobs affected will more often require a reorganization of tasks into new jobs. This process takes several years, as firms reorganize and reskill for the appropriate level of education.

Third, productivity gains create new job needs upstream in infrastructure and services, while new jobs are created downstream as a result of innovations in products and services. The total productivity gains are hence reinjected into the economy, but at a lower labor-to-capital ratio, taking into account the aggregate industry diffusion of automation, and exogenous wages.

Fourth, supply and demand of labor defines the primary impact of unemployment. We also consider a secondary impact, coming from any skill mismatch arising from technology diffusion, as automation is skill biased toward jobs that are more digital and non-routine and toward tasks that are less routine based. Total unemployment puts some pressure on wages, expressed through a Phillips curve.

Data sources for country simulations

We developed simulations for each of the nine digital front-runner countries. We relied on several external data sources to establish a baseline and calibrate our results.

The baseline is based on population forecasts from the OECD, from which we also retrieved data on historical levels and growth in productivity, GDP, and GDP per capita. We obtained data on current and historical growth of labor supply and demand by skill level, as well as historical inflow and outflow by skill level, from Eurostat.

As calibration parameters, we used data from the OECD to obtain the labor share, the average savings of companies, the countries’ trade in digital services, the skill composition of ICT jobs, the overall trade balance relative to GDP, and historical real-wage growth.

Appendix: Country specific results

Exhibit 22

Overview of impact on the economy

MIDPOINT SCENARIO

Impact towards 2030 (Automated – New job creation)

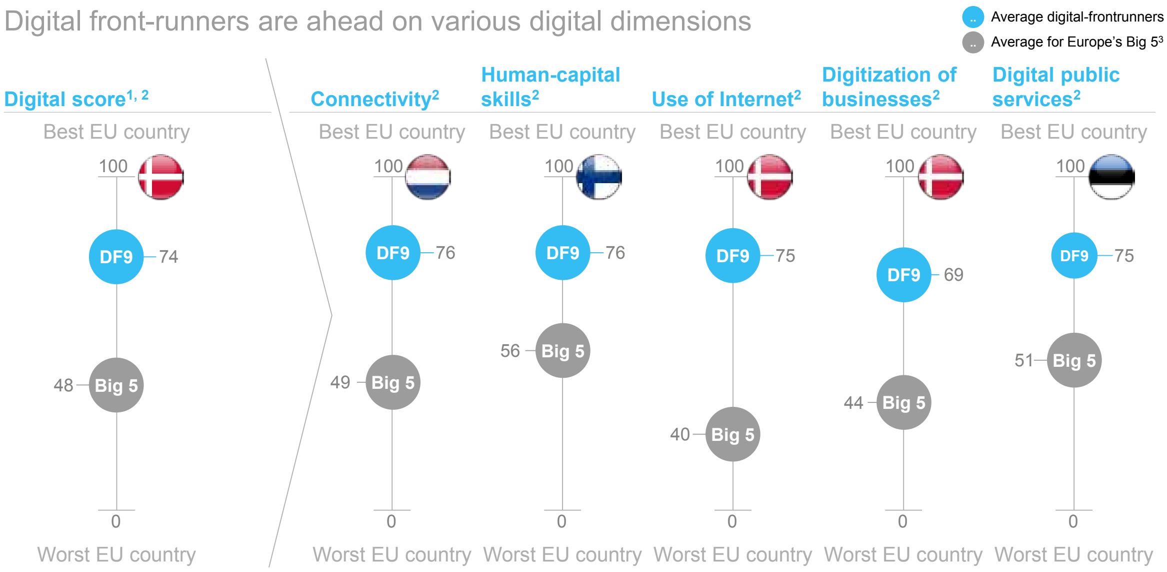
Country	Year	GDP BnEUR, real	GDP/ capita growth[1] % p.a.	Unemployment % of employees	Public sector % of employees	Automation potential % of work activities, 2016	Automated % of work activities, 2030	Job substitution % of job base	Jobs from spill over effects % of job base	New job creation % of job base	Digital jobs % of employees	High-educated labor % of employees
BEL	2016	420	1.2%	~8%	30%	42%					5%	43%
	2030	570	1.7%	~7%			25%	-15%	+10%	+6%	10%	48%
DEN	2016	280	1.2%	~6%	30%	40%					7%	35%
	2030	380	2.0%	~7%			25%	-17%	+12%	+6%	12%	39%
EST	2016	20	4.3%	~7%	21%	46%					7%	40%
	2030	30	1.8%	~6%			24%	-13%	+10%	+5%	11%	47%
IRE	2016	280	4.3%	~8%	23%	43%					7%	48%
	2030	400	2.1%	~5%			24%	-15%	+10%	+8%	13%	54%
LUX	2016	50	2.2%	~6%	29%	38%					5%	49%
	2030	80	1.6%	~5%			23%	-13%	+10%	+5%	9%	56%
NET	2016	700	1.5%	~6%	28%	45%					5%	36%
	2030	950	1.9%	~5%			28%	-17%	+12%	+7%	11%	39%
FIN	2016	220	1.2%	~9%	26%	44%					7%	44%
	2030	290	1.8%	~8%			25%	-15%	+11%	+5%	11%	51%
SWE	2016	460	1.6%	~7%	31%	46%					7%	40%
	2030	670	2.0%	~5%			28%	-17%	+12%	+6%	12%	45%
NOR	2016	340	1.5%	~5%	36%	42%					3%	43%
	2030	500	2.0%	~5%			27%	-18%	+11%	+6%	8%	45%

1 GDP/capita growth in 2016 is based on the period 1990-2015. GDP/capita growth in 2030 based on the period in 2016-2030

Source: OECD, Eurostat, McKinsey Global Institute, McKinsey analysis

Exhibit 23

Digital front-runners are ahead on various digital dimensions



1 Digital score is average score across the five dimensions shown at right.
2 Differences between best and worst scoring country on each original scale are 9 (connectivity), 11 (human-capital skills), 6 (use of Internet), 9 (digitization of businesses), and 9 (digital public services).
3 Big 5 defined as France, Germany, Italy, Spain, and the United Kingdom

Source: Digital Economy and Society Index 2017, European Commission; McKinsey

How will the world look with more AI?

Automation, artificial intelligence, blockchain and smart driverless cars may be a source of concern for many, but on reflection they are likely to bring a simpler way of living, better jobs and an improved experience in work and leisure.

The benefits do not necessarily translate into hard added value and GDP growth, but they will enhance our daily lives. Consider agriculture: With computer-vision and machine learning, technology can deliver optimal field treatment and maximize crop yields, leading to less working time for the farmer and more security of harvest. Smart transport systems will cut the number of accidents due to human error, reduce congestion and free time for commuters.

Elsewhere, lawyers and insurance companies will spend less time on document reviews, while there will be new ways to mine natural resources, without the risk of putting workers into hard physical environments.

Three case studies show how the impact of automation and AI will change our world in the years ahead:

1. Retail

Amazon is a digital native using new technologies for retailing and operations. In a 2017 letter to shareholders, founder Jeff Bezos makes references to how technology will change every touchpoint of retailing, from inventory being handled by Kiva-robotics to users ordering via AI-based voice platform Alexa, and delivery by drones.

In bricks and mortar, Amazon is planning stores without humans, where RFID technology and computer vision tools will allow any Amazon Prime member to shop without a traditional checkout process.

Obviously, not all retailers are pushing the envelope in the same way as Amazon, but they are not standing still. In a recent survey, Robotic Process Automation is already put to work in one in seven retailers, and one in five uses machine learning/analytics. The three areas of greatest opportunity in the short to medium term are promotions, assortment, and replenishment.

The use of AI in retail can generate several benefits. First, it helps people make smarter decisions, with more accurate and real-time forecasting. Good forecasts help improve supply management, define impactful thematic promotions, and optimize assortment and pricing. Second, AI can make operations more efficient, thanks to a combination of robotics and process optimizations that enhances productivity and reduces manual labor costs. AI will enable retailers to increase both the number of customers and the average amount they spend by creating personal and convenient shopping experiences.

Retailers can know more about what shoppers want – sometimes before shoppers themselves

In the future, artificial intelligence could help forecast and automate retailers' decision making in real time. By identifying and learning from patterns in large volumes of data, spanning many disparate sources – previous transactions, weather forecasts, social media trends, shopping patterns, online viewing history, facial expression analysis, seasonal shopping patterns – AI can help companies adjust to and master an increasingly dynamic market environment. By improving forecasting accuracy, machine learning and computer vision can help better anticipate consumer expectations while optimizing and automating supplier negotiations.

The impact of AI-enabled forecasting is already being demonstrated. For instance, a European retailer was able to improve its earnings before interest and taxes (EBIT) by 1 to 2 percent by using a machine learning algorithm to anticipate fruit and vegetables sales. The company automatically orders more produce based on this forecast to maximize turnover and minimize waste. Similarly, German e-commerce merchant Otto has cut surplus stock by 20 percent and reduced product returns by more than two million items a year, using deep learning to analyse billions of transactions and predict what customers will buy before they place an order. The system is 90 percent accurate in forecasting what the firm will sell over the next 30 days, so Otto allows it to order 200,000 items a month from vendors with no human intervention.

Autonomous robots can work alongside people to increase productivity and reduce injuries. Swisslog has reduced stocking time by 30 percent since it began using autonomous guided vehicles in its warehouses. DHL unleashed a pair of fully automated trolleys last year that follow pickers through the warehouse and relieve them of physical work.

In store, machine learning can help optimize merchandising, with opportunities to improve assortment efficiency by 50 percent. A retailer was able to generate a sales uplift of 4 to 6 percent by using geo-spatial modelling to determine micromarket attractiveness and leveraging statistical modelling to predict and minimize running out of stock. With machine learning, these efficiencies would be realized in real time and would gain in accuracy as they learn from new data.

Ocado, a UK online supermarket, is one company that has embedded AI at the core of its operations. In the retailer's warehouse, machine learning algorithms steer thousands of products over a maze of conveyor belts and deliver them to humans just in time to fill shopping bags. Other robots whisk bags to deliver vans whose drivers are guided by an AI application that picks the best route based on weather and traffic conditions.

Retailers are getting personal

Empowered by the ease, economy, and immediacy of online shopping, many consumers already expect personalized, immediate, pitch-perfect help. In the future, AI will be invaluable to marketers trying to reach hyperconnected consumers who continuously redefine value by comparing prices online – even, and particularly, when browsing in a non-digital store. Smartphone penetration necessitates an omni-channel strategy, and AI can help optimize, update, and tailor it to each shopper in real time. Insights-based selling, including personalized promotions, optimized assortment, and tailored displays, could increase sales by 1 to 5 percent. Online, this kind of personalization, combined with dynamic pricing, can lead to a 30 percent growth in sales.

Carrefour reported a 600 percent increase in app users after it deployed beacons in just 28 stores.

What's in it for the user?

1. Personalized and contextualized promotions
2. Delegation of shopping via voice-automated platforms
3. Fast, integrated tech delivery of goods to the home, car etc.

What's in it for the employer?

1. Less time spent on heavy logistics; pick and pack and shelf stacking
2. Move time interfacing with clients and guiding them into new retail discoveries
3. Development of new concierge services

2. Electricity Utility

The electric utilities sector has great potential to embrace artificial intelligence in the coming years. At every step of the value chain, from power generation to end consumers, opportunities for machine learning, robotics, and decision-making automation exist that could help electric utilities better predict supply and demand, balance the grid in real time, reduce downtime, maximize yield, and improve end-users' experience. In one survey, energy companies are already investing heavily, with 18 percent implementing robotics at scale.

Electric utilities are starting to explore artificial intelligence AI startup bought by Google in 2014, is currently working with National Grid to predict supply and demand peaks in the United Kingdom by using weather-related variables and smart meters as exogenous inputs, hoping to cut national energy usage by 10 percent and maximize the use of renewable power despite its intermittence.

In the future, machine and deep learning technologies could forecast demand and supply in real time and optimize load dispatch, thereby saving energy and cost. For a network that experiences demand ranges between 10 and 18 gigawatts, saving could reach 100 megawatts over periods of one to four hours per day. More reliable forecasts would allow utilities to delay or even avoid ramping up a fossil-fuel-powered station. It would also offer cost-effective alternatives to operators, who currently consider building new plants to absorb seemingly impossible variability.

Grid modernization and deployment of smart meters are already under way in most countries. In Europe, Sweden and Italy have replaced nearly all meters with smart meters.

AI could also help utilities assesses the reliability of new small supply players, such as households, by predicting the lifetime of their storage units and their suitability for integration in a power storage scheme.

Yield optimisation, predictive outage, and preventive maintenance can help better plan the grid.
The other lever where AI and robotics could help reduce costs is operations, from power generation to transmission and distribution.

With AI, power providers could maximize their generation efficiency with real-time adjustments across assets. For instance, machine learning can help optimize wind turbines' yield based on their own past performance, real-time communication with other wind farms, the grid status, and changes in wind speed and direction. GE Renewables recently introduced a "digital wind farms" concept, which optimizes yields with machine learning applied to turbine sensors data, and modular turbines that can be customized to conditions at each installation site. GE says the technology could boost a wind farm's energy production by as much as 20 percent and create $100 million in extra value over the lifetime of a 100-megawatt farm.

Power generation yield can also be bolstered by reducing downtime and improving preventive maintenance. To date, preventive maintenance efforts have had a limited impact because firms can be overwhelmed by the sheer volume of sensor data and inaccurate alerts. This is an opportunity for AI technologies, which thrive on mountains of information. Advanced analytics already demonstrate the benefit of intelligent maintenance. Some coal power plants, for instance, were able to predict the timing of failures within one week six to nine months in advance, with 74 percent accuracy. Overall, we estimate that optimizing preventive maintenance, automating fault prediction, and increasing capital productivity through AI applications could increase power generation earnings before interest, taxes, depreciation, and amortization (EBIDTA) by 10 to 20 percent.

AI can transform the user experience with consumption tailoring and automation for more convenience
Energy consumers also can benefit from AI. Since the liberalization of energy retailing, new entrants have piled into the market. In Europe, customers can choose from more than 20 suppliers, many competing on price alone. AI can help understand consumption patterns, tailor the value proposition as well as consumption to the users' preferences, and limit the hurdles for switchers.

Machine learning can help consumers deal with the complex tasks of selecting their electricity supplier based on users' preferences in terms of pricing and energy generation type, as well as metering measurements. Lumator has developed software with Carnegie Mellon University in Pittsburgh, Pennsylvania, that scans the market for the most suitable electricity supply deal. Lumator claims it can save people between $10 and $30 a month on their bills. In the future, AI could automatically switch energy plans, without consulting consumers or interrupting service, as the best deals become available for that specific user's profile.

What's in it for the user?

1. More efficient energy use and lower bills
2. A way to produce and exchange P2P energy
3. Insurance against outages

What's in it for the employer?

1. Less workforce time in dangerous outage situations/ on turbines etc.
2. New brand experiences and service models, e.g., P2P electricity sales

3. Health Care

There is enormous potential in Artificial Intelligence's ability to draw inferences and recognize patterns in large volumes of patient histories, medical images, epidemiological statistics, and other data. AI has the potential to help doctors improve their diagnoses, forecast the spread of diseases, and customize treatments. Artificial Intelligence combined with health care digitization can allow providers to monitor or diagnose patients remotely as well as transform the way we treat the chronic diseases that account for a large share of health-care budgets.

In any case, the success of AI-based tools in medicine will hinge on whether public officials sign on and pitch in with financing, research support, and legislation that protects patients' privacy and gives medical professionals access to anonymized data on illnesses, treatments, and outcomes to teach computers how to identify and treat a wide range of maladies.

Making these changes will not be easy. But there are considerable rewards for success: AI is capable of improving care while reducing costs – no small matter when health-care spending globally reached 9.9 percent of GDP in 2014 (it was 11.5 percent in France and 17.1 percent in the United States), according to the World Health Organization.

But despite AI's potential, health care currently trails other industries in adopting the technology, according to our survey. AI use is concentrated in operations and customer service; the technologies adopted most often are speech recognition and computer vision, by 9 and 7 percent, respectively, of health care companies in our survey sample, which included organizations that already were aware of AI. In most hospitals, operations management functions such as appointment scheduling are still done manually.

This slow progress does not stem from a lack of interest among medical professionals and executives. Rather medicine faces some uniquely high hurdles to adoption. The sensitive nature of medical records and strict regulations to keep them private has stymied the collection of the high-quality aggregated data required by deep learning applications and other AI tools. Also slowing adoption are the complexity of both that data and the industry itself, the fragmentation of the health-care industry, and other regulatory barriers.

AI can identify public-health threats and the most at-risk patients

AI technology adoption rates are low. The most advanced application area currently is payment and claims management supported by machine learning algorithms. Some clinicians are using AI to forecast the spread of a certain diseases and try to anticipate which patients would be most likely to succumb. Armed with this information, they offer preventive care. They also use the forecasts to help hospital administrators schedule staff members, negotiate reimbursement rates with insurers, set budgets, and optimize inventory levels.

This idea of leveraging medical and social data to better manage costs has made forecasting one of the few areas of active AI applications in health care, attracting top tech pharma, and medical players as well as small startups. Johnson & Johnson, in partnership with SAP, has used machine learning to anticipate customer demand, inventory levels, and product mix. Careskore, a predictive analytics platform, uses machine learning to determine the likelihood of a patient's being readmitted to a hospital.

Indeed, in the future, AI tools will enable health care to dramatically accelerate its shift toward preventive medicine. Medical professionals will focus on managing patient's health remotely and keeping them out of hospitals. To do this, AI tools will analyse not only patients' medical histories but also environmental factors that can influence health, such as pollution and noise where they live and work. This can identify risk groups and inform local authorities' decisions about where to implement preventive-care programs.

AI can help medical professionals diagnose disease and improve operations

Machine learning has enormous potential to enhance diagnostics accuracy. The Sloan Kettering Institute estimates that doctors use only 20 percent of the available trial-based knowledge when diagnosing cancer patients and prescribing treatment. AI applications can sift through millions of pages of medical evidence to provide a diagnosis and treatment options in seconds.

AI-based image recognition and machine learning can see far more detail in MRI and X-ray images than human eyes can register. For example, different types of glioblastomas have distinct genetic abnormalities, and doctors treat each one based on those abnormalities. But radiologists cannot identify genetic abnormalities of these brain cancers from images alone. The Mayo Clinic has a machine learning program that can quickly and reliably identify the abnormalities.

AI-powered automation has the potential to increase health care productivity by relieving doctors and nurses of routine activities. Someday, chatbots equipped with deep learning algorithms could relieve emergency room personnel of tending to large numbers of walk-in patients with non-emergencies like sore throats and urinary tract infections.

Health insurers can devise new ways to encourage preventive care and incentivize providers

The ability of machine learning technologies to predict patient behaviour and calculate disease probabilities better than current methods will lift the profitability of life- and health-insurance providers.

New business models can use AI combined with behavioural health interventions to focus on prevention, disease management, and wellness-addressing unhealthy behaviors before people become patients. A South-African insurer, Discovery Health, tracks the diet and fitness activity of people it insures and offers incentives for healthy behaviours.

AI also will encourage new partnerships among payers, providers, and pharma companies and will facilitate pay-for-performance models that will accelerate the shift towards preventive care. Payers may become more involved in care management or encourage their providers to so by introducing contract models based on risk uncovered by machine learning or the potential for AI-based risk-management modelling.

Episode-base payment plans, which reimburse doctors and hospitals based on the average cost of treatment across all providers in the group, will be significantly extended when more insurers uses machine learning to analyse historical inpatient data. Based on McKinsey's client experience, we believe that this approach can have a clear impact on costs, reducing orthopaedic surgeons' fee by 8 to 12 percent and the fees paid to diagnosing physicians by 4 to 5 percent.

What's in it for the user?

1. Lower bills
2. Better diagnosis and prevention – better triage of appointments
3. On-demand medicine (more real time and personalized), shorter waiting times

What's in it for the employer?

1. Better diagnosis tools
2. Effective choice of visits (virtual etc.)
3. More successful hospital operations and less complex surgery; less nursing actions.


20%
10%

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