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NOTES FROM THE AI FRONTIER

TACKLING EUROPE'S GAP IN DIGITAL AND AI

DISCUSSION PAPER

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IN BRIEF

NOTES FROM THE AI FRONTIER: TACKLING EUROPE'S GAP IN DIGITAL AND ARTIFICIAL INTELLIGENCE

Europe's digital gap with the world's leaders is now being compounded by an emerging gap with the world's leaders in its development and adoption of artificial intelligence (AI) technologies. Without faster and more comprehensive engagement in AI, that gap could widen. Europe may not need to compete head to head but rather in areas where it has an edge (such as in business-to-business [B2B] and advanced robotics) and continue to scale up one of the world's largest bases of technology developers into a more connected Europe-wide web of AI-based innovation hubs.

- Digitisation is an important technical and organisational precondition for the spread of AI, yet Europe's digital gap—at about 35 percent with the United States—has not narrowed in recent years. Early digital companies have been the first to develop strong positions in AI, yet only two European companies are in the worldwide digital top 30, and Europe is home to only 10 percent of the world's digital unicorns.
- Europe has about 25 percent of AI startups, but its early-stage investment in AI lags behind that of the United States and China. Further, with the exception of smart robotics, Europe is not ahead of the United States in AI diffusion, and less than half of European firms have adopted one AI technology, with a majority of those still in the pilot stage.
- If Europe develops and diffuses AI according to its current assets and digital position relative to the world, it could add some some €2.7 trillion, or 19 percent, to output by 2030. Such an impact would be roughly double that of other general-purpose technologies adopted by developed countries in the past.
- Europe's ability to capture the full potential of AI varies significantly among sectors and countries. With the exception of some Scandinavian countries and the United Kingdom, Europe lags behind the United States in readiness for AI. If laggard European countries were to close the current readiness gap with the United States, Europe's GDP growth could accelerate by another 0.5 point a year, or an extra €900 billion, by 2030.
- Delay in AI diffusion could further erode Europe's digital position in favour of other geographies. Embracing AI is nonetheless likely to cause labour dislocation and potentially create new risks around potential misuse. Frictional unemployment and income wage inequality could increase as the skill shifts associated with AI adoption take time to implement. However, if the transition is dealt with effectively, firms and governments that leverage AI could create sufficient new opportunities that deliver new occupations and jobs to compensate for digital automation, especially if and when Europe chooses to innovate sufficiently to close its AI gap with the United States and to expand its local AI ecosystems.
- To scale up and close the gap with the world's AI leaders, Europe will need to focus on five priorities: (1) continued development of a Europe-wide, vibrant ecosystem of deep tech and AI startups; (2) acceleration of digital transformation and AI innovation among incumbent firms; (3) progress on the digital single market; (4) fundamental development of research, education, and practical skills; and (5) bold thinking about how to guide societies through the potential disruption.

INTRODUCTION

On many metrics, the European economy and its businesses have been grappling for years to capture the full potential of current and even previous generations of digital tools.[1] A successful digital transformation is more important for Europe at a time when new digital technologies, such as artificial intelligence (AI) are increasingly being adopted.

Recent advances in robotics and AI are pushing the frontier of what machines are capable of doing in all facets of business and the economy.[2] Although for smart machines to master more sophisticated tasks—let alone to acquire the dynamic intelligence of humans—might still take years, machine learning and analytics have already penetrated many industries, and the scope of that penetration is poised to grow rapidly in the years ahead.

European companies are not standing still on AI. They are slowly piloting and using those technologies, motivated by the judgement that automation and AI are likely to drive the largest growth opportunities in the region. In one recent survey, at least 55 percent of corporate respondents took this view.[3] Europe may risk falling further behind, however, as the world's AI leaders, the United States and China, continue to forge ahead aggressively on AI adoption and diffusion. Moreover, the field competing in the AI race is expanding, with countries including Canada, Japan, and South Korea making strides.[4]

Europe undeniably has many strengths, including an increasing number of thriving digital hubs, a large set of world-class research institutions, what could become the largest single digital market in the world, and what seems to be the largest and fastest-growing pool of professional developers.[5] Drawing on the best thinking on AI, and previous McKinsey Global Institute (MGI) analysis on AI that leverages its unique micro-to-macro approach to analyse AI ecosystems, we argue that Europe needs to tackle its fragmented AI ecosystem and support faster absorption of AI technologies by European companies to generate and internalise the productivity benefits they offer.[6]

Embracing AI is challenging for companies and the technology comes with both limitations and risks, as we have noted in prior research.[7] Policy makers and business leaders will need to think boldly about ways to mitigate the potential labour implications, including workplace disruption and new skills requirements, and the risk of exacerbating social inequality. Issues such as malicious use, abuse of data privacy, and cybersecurity will also require careful thought and targeted measures.[8]

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1 *Digital Europe: Pushing the frontier, capturing the benefits,* McKinsey Global Institute, June 2016.

2 For an overview of AI technologies and use cases, see *The age of analytics: Competing in a data-driven world,* December 2016; and *What's now and next in analytics, AI, and automation,* McKinsey Global Institute, May 2017.

3 See *European business: Overcoming uncertainty, strengthening recovery,* McKinsey Global Institute, May 2017; and *How digital reinventors are pulling away from the pack,* McKinsey & Company, survey, October 2017.

4 See *AI Singapore,* National Research Foundation, Prime Minister's Office, Singapore (https://www.nrf.gov.sg/programmes/artificial-intelligence-r-d-programme); Artificial Intelligence Research Center, Government of Japan (https://www.airc.aist.go.jp/en/intro/Brochure_en.pdf); Mark Zastrow, "South Korea's Nobel dream", *Nature,* Volume 534, 2016; and Pan-Canadian Artificial Intelligence Strategy, CIFAR (https://www.cifar.ca/ai/pan-canadian-artificial-intelligence-strategy).

5 *The state of European tech 2017,* Atomico (https://2017.stateofeuropeantech.com/).

6 See *The age of analytics: Competing in a data-driven world,* McKinsey Global Institute, December 2016; *Harnessing automation for a future that works,* McKinsey Global Institute, January 2017; and 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.

7 *AI, automation, and the future of work: Ten things to solve for,* McKinsey Global Institute, June 2018; and Michael Chui, James Manyika and Mehdi Miremadi, "What AI can and can't do (yet) for your business," *McKinsey Quarterly,* January 2018.

8 *Jobs lost, jobs gained: Workforce transitions in a time of automation,* McKinsey Global Institute, December 2017; *Skill shift: Automation and the future of the workforce,* McKinsey Global Institute, May 2018; and Miles Brundage et al., *The malicious use of artificial intelligence: Forecasting, prevention, and mitigation,* February 2018.

This paper builds on two important new perspectives (see Box 1, "Two new perspectives to better gauge AI provision and use by European firms"). First, we blended the findings of authoritative secondary research sources with three primary independent global surveys at the corporate and sector levels conducted in 2017 and 2018 to better gauge how firms anticipate the way AI might unfold in Europe. Second, we updated MGI's comprehensive

Box 1. Two new perspectives to better gauge AI provision and use by European firms

This paper is the latest publication in MGI's ongoing research on automation, AI, and the future of work.[1] It is the fourth in MGI's *Notes from the AI frontier* series. In 2018, we published three reports in the series. In December, we discussed AI's potential to help tackle some of the world's most challenging social problems. In September, we modelled the potential global impact of AI, and we use that model for this analysis of Europe. In April, we analysed more than 400 use cases across 19 industries and nine business functions, highlighting the broad use and significant economic potential of advanced AI technologies.[2]

A great deal of external research is devoted to the way AI is developing in economies around the world, but most of it either focuses on the universe of startups or presents only an aggregate view on the way AI can affect economic productivity. Here, we provide what we believe to be a more solid analysis on the likely effect of these technologies based on explicit modelling of that impact that uses econometrics to estimate the mechanisms of corporate diffusion of AI. We complement this modelling with secondary data sources and new research on how corporates may choose to adopt and use AI in Europe.

Data sources

We blended secondary data from three essential sources—the European Commission Directorate-General for Research and Innovation (which compiles data from Eurostat and other public sources), CB Insights, and Atomico (the latter two as authoritative sources on the state of AI-based deep tech in Europe)—to generate a deep dive into AI ecosystems and produce new results. We assess, for instance, how the production of AI startups by EU member states could be increased if Europe were to overcome current fragmentation and develop a network of connected AI innovation hubs.

We also build on three independent surveys of executives to develop a micro-to-macro approach on how corporate demand for AI is likely to develop economically in Europe (see the technical appendix at the end of this paper for details on those surveys).

The first survey that informs this work was conducted by MGI in 2017 and was published as part of research unveiled at the VivaTech 2017 conference.[3] The survey asked global companies about their adoption of AI technologies and the enablers and constraints the companies were encountering. The more than 3,000 respondents lived in ten countries around the world, including France, Germany, Poland, Sweden, and the United Kingdom. Respondents represented companies in 14 sectors of the economy that range in size from fewer than ten to more than 10,000 employees. The survey collected data on the business objectives behind technology adoption and the extent of AI use. That data enabled us to

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1 See, for instance, *Jobs lost, jobs gained: Workforce transitions in a time of automation,* McKinsey Global Institute, December 2017; and *Skill shift: Automation and the future of the workforce,* McKinsey Global Institute, May 2018.

2 See *Notes from the AI frontier: Applying AI for social good,* December 2018; *Notes from the AI frontier: Modeling the impact of AI on the world economy,* September 2018; and *Notes from the AI frontier: Insights from hundreds of use cases,* April 2018. Also in April 2018, we published a data visualisation showing the potential value created by AI and other analytics techniques in 19 industries and nine business functions. See *Visualizing the uses and potential impact of AI and other analytics,* McKinsey Global Institute, April 2018.

3 *Artificial intelligence: The next digital frontier?,* McKinsey Global Institute, June 2017.

global model of the diffusion of AI developed for our early research on AI for the EU-28, in particular integrating a perspective on the development of AI startup ecosystems in Europe.[9]

9 The EU-28 modelling is part of a global model whose results were published in September 2018. See *Notes from the frontier: Modeling the impact of AI on the world economy,* McKinsey Global Institute, September 2018.

separate early adopters from others to understand the effect of technology use on company performance (see the appendix for further details on methodology).

In 2018, we posed the same set of questions to a narrower list of companies that are members of the European Business Summit. That survey (sourced independently from a different provider than the survey used at VivaTech) added more questions relating to how AI adoption could affect each company's hiring, mix of skills, and capital investment. Posing those questions provided better visibility into whether AI will complement or substitute for workers and capital.

Finally, McKinsey conducts an online survey each year on digital trends and the use of digital technologies for business reinvention.[4] The most recent survey, undertaken in 2018, covers 20 of the EU-28 nations, China, and the United States. This survey focuses mostly on large companies. We added questions on the adoption and use of AI technologies so that we could assess the effect of each wave of digital technologies on business decisions and performance. The sample covers more than 1,600 corporations, of which 650 are headquartered in Europe.

To get a sense of sector readiness for AI, data have been merged to create subsamples of sufficient size for ten industries: manufacturing, transport and travel, telecoms and media, information and communications technology (ICT), utilities, financial services, professional services, retailing, construction, and primary resources.

Modelling

Leveraging early work, we updated a comprehensive model of how AI can affect each of the EU-28 economies.[5] The model's building blocks include important channels by which AI can affect profitability (from labour automation to new products and services) to assess global competition in AI. Channels include international flows between countries and between Europe and elsewhere and reinvestment of productivity gains into economies that is larger the more successful Europe is in building its own AI supply chain. The model is either calibrated directly with the survey data or induced from the data. For example, we use detailed econometrics at the firm level to estimate the likelihood of companies deciding to adopt AI. Emerging from the econometric results are statistically robust insights into the role AI dynamics play among firms in terms of profitability and employment. The dynamics and effect depend on why AI is being used—for instance, for pure efficiency or for launching new products and services.[6]

4 See Jacques Bughin, Laura LaBerge, and Anette Mellbye, "The case for digital reinvention", *McKinsey Quarterly,* February 2017; and Jacques Bughin, Tanguy Catlin, Martin Hirt, and Paul Wilmott, "Why digital strategies fail", *McKinsey Quarterly,* January 2018.

5 *Notes from the frontier: Modeling the impact of AI on the world economy,* McKinsey Global Institute, September 2018.

6 Some important relationships highlighted by econometric modelling are highlighted in, for instance, Jacques Bughin and Jeongmin Seong, "How competition is driving AI's rapid adoption", *Harvard Business Review,* October 17, 2018; and *Assessing the economic impact of artificial intelligence,* ITU Trends, International Telecommunication Union, Issue Paper number 1, September 2018.

1. EUROPE IS ADDING AN AI GAP TO ITS DIGITAL GAP

Europe already lags behind the world leader on the supply, as well as the adoption and diffusion, of digital technologies—the United States. Now that digital gap is spilling over into an AI gap. The way that companies are developing digital tools and using them in their organisations is arguably the most important precondition for the spread of AI; therefore, Europe's persistent digital gap affects its ability to leverage fully the promise of AI.[10]

EUROPEAN ECONOMIES ARE DIFFUSING DIGITAL—THE FOUNDATION OF AI—AT A RELATIVELY SLOW PACE

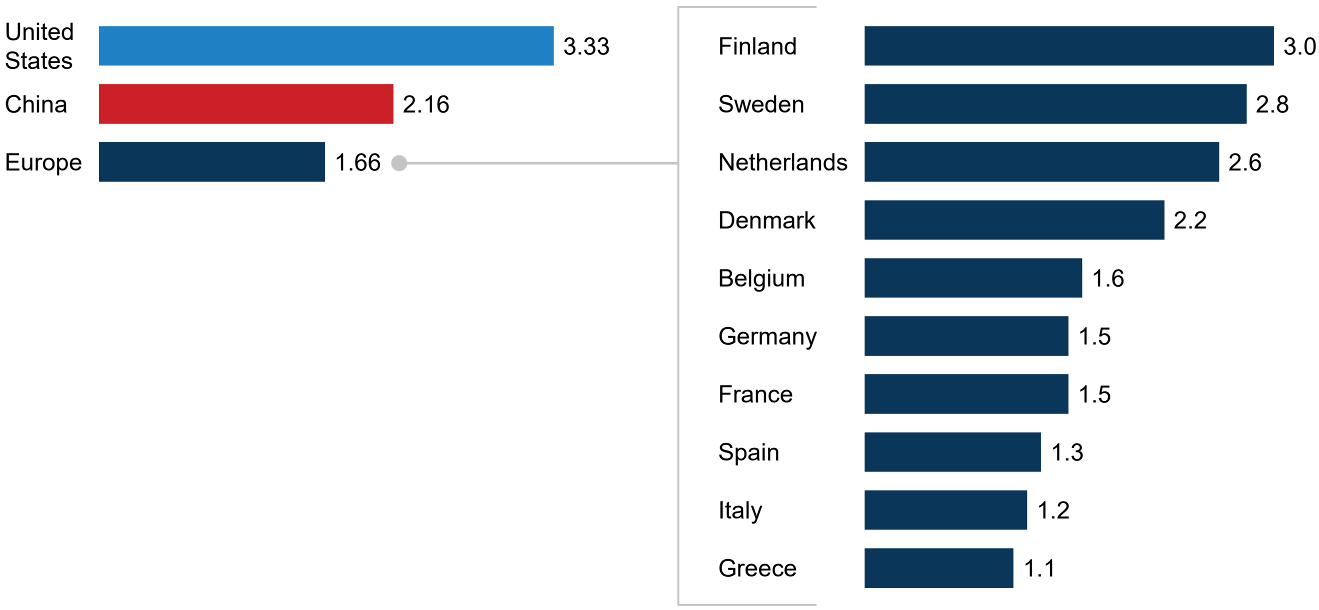
Europe is not standing still on digital and AI. Some metrics suggest considerable momentum with, for instance, four times more capital invested than five years ago in tech, and with close to six million professional developers—more than in the United States.[11] Nevertheless, Europe may need to accelerate efforts to develop digital technology and, therefore, AI. As is well documented, Europe is falling behind the United States and some Asian countries—most notably China—in terms of developing digital technology leaders.

Although Europe's GDP is comparable to that of the United States and just ahead of China's, the digital- and AI-based portion of Europe's ICT sector today accounts for around 1.7 percent of GDP, rather lower than the share in China at 2.2 percent and only half the 3.3 percent share in the United States (Exhibit 1).[12]

Exhibit 1

Europe lags behind the United States and China on digital ICT.

Digital ICT 2017[1]
% of GDP, estimate



1 Digital share of ICT value added is estimated by taking the share of revenue made through digital channels and by taking the portion of cost of all functions performed digitally.

SOURCE: Directorate-General for Research and Innovation, European Commission, 2018; McKinsey Digital Survey, 2018; McKinsey Global Institute analysis

[10] For further discussion, see *Notes from the AI frontier: Modeling the impact of AI on the world economy,* McKinsey Global Institute, September 2018.

[11] *The state of European tech 2017,* Atomico (https://2017.stateofeuropeantech.com/).

[12] We use the share of sales and the online supply chain to compute the digital share of value added in the ICT sector. Data for online share are consistent between the Eurobarometer and the 2018 McKinsey survey used for digitisation in this paper. Statistics on the value-added share of ICT in Europe and other countries come from the European Commission Directorate-General for Research and Innovation.

At the end of 2017, Europe was not home to any of the ten largest internet companies worldwide. Looking at startup companies, in the United States the capital invested was about €220 per capita, whereas in Europe per capita investment was as low as €3 in Italy, €58 in Finland, and €123—the highest share in Europe—in Sweden. Europe had only 10 percent of the world's 185 "unicorns"—private startups with a value of at least $1 billion—compared with 54 percent in the United States. China had 23 percent (or 42 companies) of the world's unicorns in February 2017. Each of the EU-28 countries' balance of digital goods and services with the United States has been systematically negative, in complete contrast with the balance of traditional goods and services.[13] Europe has a large pool of developers; however, more of them seem to be moving from Europe to the United States (accounting for 32 percent of developers leaving Europe) than are US developers moving to Europe (16 percent of incomers, most of whom are moving to the United Kingdom).[14]

The US digital ecosystem—largely based in hubs such as Silicon Valley, Seattle, and Boston—is large, innovative, and diverse, encompassing research institutions, universities, and private companies. In 2015, the top ten Silicon Valley startups achieved turnover ICT of approximately $600 billion.[15] Moreover, leading US digital platforms have achieved capital-market value similar to that of leading industrial companies such as Siemens.[16]

Possibly less known, large Western European companies are continuing to expand their use of early digital technologies, but the pace of diffusion remains low, with the share of fully digitised companies increasing by less than 10 percent a year between 2010 and 2016 (a finding consistent with data collected by the European Commission).[17] Recent technological waves such as cloud-based technologies have only been adopted by a majority of large companies in Western European countries, such as Finland; other technologies, such as the Internet of Things, remain niche, as is the use of big data and the development of related big data infrastructure, such as data lakes (Exhibit 2).

MGI research in 2016 found that European countries were capturing only 12 percent of their full digital potential (defined as weighted deployment of digital assets, labour, and practices across all sectors, compared with the most digitised sector)—two-thirds of the captured potential in the United States.[18] Using the most recent data from McKinsey's Digital Survey in 2017, the same gap remains (see Box 2, "An update on the digital gap between Europe and the United States").

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13 Estrella Gomez-Herrera, Bertin Martens, and Geomina Turlea, "The driver and impediments for cross-border e-commerce in the EU", *Information Economics and Policy,* Volume 28, Issue c, 2014.

14 *The state of European tech 2017,* Atomico (https://2017.stateofeuropeantech.com/).

15 Tobias Kollmann, *Digital leadership,* Bundestag der Immobilien- und Vermögenstreuhänder, Vienna, Austria, September 21–23, 2015, (http://bundestag.at/2015/wp-content/uploads/2015/09/kollmann-digital-leadership.pdf).

16 Despite experiencing a digital gap, Europe is not without some strong companies built on digital technology. It is home to some large digital companies, such as Spotify, Supercell, Karna, and Farfetch, and they are growing rapidly.

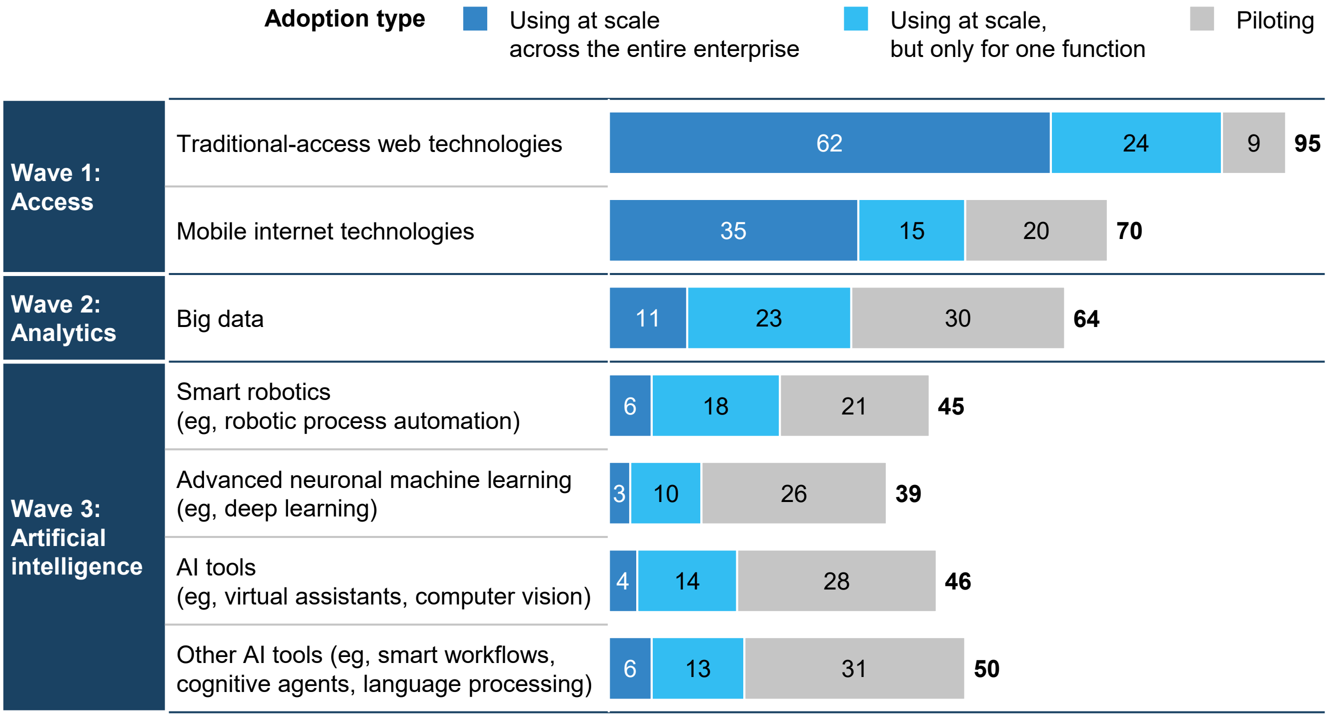
17 See *Integration of digital technology by enterprises,* European Commission (https://ec.europa.eu/digital-single-market/en/integration-digital-technology). The data for Europe integrates small and medium-size businesses well and shows that the diffusion dynamics create a real gap between Western advanced countries such as in Scandinavia, and less advanced Eastern countries such as Romania where the pace of diffusion remains weak.

18 *Digital Europe: Pushing the frontier, capturing the benefits,* McKinsey Global Institute, June 2016. For a full explanation of the methodology, see the technical appendix of *Digital America: A tale of the haves and have-mores,* McKinsey Global Institute, December 2015. The European Commission's Digital Economy and Society Index (DESI) finds similar disparities. Denmark, for example, ranks at the top of the list, with a composite score nearly twice as high as that of Romania, which sits at the bottom. See The Digital Economy and Society Index (DESI), European Commission (https://ec.europa.eu/digital-single-market/en/desi).

Exhibit 2

Europe is in the early stages of diffusion of AI technologies.

% of European large companies adoption, 2017



NOTE: Figures may not sum to 100% because of rounding.

SOURCE: McKinsey Digital Survey, 2018; McKinsey Global Institute analysis

NOW EUROPE IS ADDING AN AI GAP TO ITS DIGITAL GAP WITH THE WORLD'S LEADERS

AI is nascent—at a similar stage of diffusion as Enterprise 2.0 and mobile technologies 15 years ago. Although, as some argue, Europe has deep tech talent, and European leaders acknowledge the importance of these technologies, Europe's disadvantage in digital diffusion seems likely to spill over into AI, where a new gap is appearing. Europe is not standing still on AI but needs to move faster—and on a greater scale—or risk being left further behind the world's AI leaders.

Europe has some solid foundations for the diffusion of AI

Europe was a pioneer in testing and developing AI technologies. The first autonomous car—a German Mercedes—was the first autonomous car in the world. Germany's Konrad Zuse built Z1, the world's first programme-controlled computer, in the 1930s. Thirty-five percent of deep-learning models running in the world were invented in Europe.[19]

Europe today is also buoyant when it comes to developing new AI applications. Cities such as Copenhagen, Lisbon, Munich, and Zurich have emerged as entrepreneurial deep tech hubs at the frontier of computer science—where developers are making pioneering advances in what machines can do—taking their place alongside Berlin, London, and Paris. European AI startups more than tripled from 2011 to 2016. European venture-capital-backed companies such as Graphcore, Improbable, Lilium, and Unity are competing successfully against the best US ones and supporting major AI-based ecosystems in Europe.

[19] See Jürgen Schmidhuber's home page (http://people.idsia.ch/~juergen/).

Europe also has deep tech talent, with top university centers in AI and computer science, especially in France, Germany, Switzerland, and the United Kingdom. Europe is steadily adding science, technology, engineering, and mathematics (STEM) graduates to its workforce—and doing so at a slightly faster pace than the United States. The continent managed to increase the annual total of doctoral graduates in STEM fields by some 50 percent in only a decade. Looking specifically at software developers, Europe today has 5.7 million professionals (compared with 4.4 million in the United States), and the European number has been growing at a brisk clip of 10 percent annually (although, we should note, at only 4 to 5 percent in the past two years). Germany leads the way, with almost 850,000 developers, a number that jumped by 18 percent from 2016 to 2017. The United Kingdom is second, with 830,000.[20]

Moreover, policy makers are increasingly realising that ensuring Europe's place among global AI leaders must be a priority. French president Emmanuel Macron, for example, recently announced a €1.5 billion investment to support AI research and AI startups, and many other countries—including Germany, Finland, and the United Kingdom—have announced strategic AI plans.[21] The European Commission announced that it is investing some €2.6 billion in AI and robotics development as part of its Horizon 2020 plan (and roughly the same amount in high-performance computing). The European Commission also estimates that another €2.1 billion in private investment will go into one of the world's biggest civilian research programmes on smart robots.[22]

As many of AI's previous technical challenges are overcome, European businesses are also entering the AI supply chain.[23] For instance, Spotify, headquartered in Sweden, provides tens of millions of its digital subscribers with "Discover Weekly", internally developed, AI-curated, personalised playlists of new music based on insights into customers' tastes. UK-based online retailer Ocado has developed its own smart robotics platform to build its full retail logistics. It also uses AI applications to manage logistics flows, limit fraud, and personalise online offerings. Ocado is now delivering this platform-as-a-service for many high-street retailer brands. Connecterra in the Netherlands is using AI to make agriculture more efficient and therefore sustainably feed future generations. Volvo Car Group recently earmarked 4 to 5 percent of its annual revenue to deploying new electric car innovations, many of which are enabled by AI and connectivity.[24]

Europe's investment in, and its use of, AI already lag behind that of the world's AI leaders

Nevertheless, AI initiatives remain fragmented in Europe, and investment in AI is nothing like the size of that in the United States or China. Consider, for instance, that the €2.6 billion investment in AI and robotics announced by the European Commission is only slightly larger than the amount that China is spending ($2.1 billion) on a single AI technology park in a western suburb of Beijing.[25] It is notable that Europe does not have its own version of the United States' Defense Advanced Research Projects Agency (DARPA), which makes strategic investments in breakthrough technologies deemed to be vital to national security.[26] On the AI supply chain, Europe's competitive advantage lies more in aerospace and pharmaceuticals than in sectors that are the foundations of AI, such as the internet, chip manufacturing, and semiconductors.

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[20] Ibid.

[21] Nicholas Thompson, "Emmanuel Macron talks to Wired about France's AI strategy", *Wired,* March 31, 2018.

[22] Factsheet: Artificial intelligence for Europe, European Commission (https://ec.europa.eu/digital-single-market/en/news/factsheet-artificial-intelligence-europe).

[23] Jacques Bughin and Eric Hazan, "The new spring of AI", *The Global Dispatches,* September 12, 2017.

[24] "Fueling the automotive revolution", *The Telegraph,* November 13, 2017.

[25] Christina Larson, "China's massive investment in artificial intelligence has an insidious downside", *Science,* February 8, 2018.

[26] AI spending numbers come from previous MGI research. See *Artificial intelligence: The next digital frontier?* McKinsey Global Institute, June 2017.

Box 2. An update on the digital gap between Europe and the United States

We used McKinsey's 2018 Digital Survey, which was answered by just over 1,600 executives, to segment companies by state of absorption of technologies, in particular how broadly they were adopting digital technologies and, when they were, how far they were scaling up in new workflows, applications, and services to generate returns on their digital investment.

About 80 percent of European companies claim to have generated a positive return from their digital transformation, but only 50 percent have achieved a return of more than their weighted cost of capital; the average return was 14 percent.

We find that European companies are less mature both in their state of diffusion of digital technologies and in their use of those technologies for new services and business models. Europe's use of digital technologies is biased toward traditional incumbents, in contrast to the situation in the United States. We find that the gap between Western Europe and the United States has remained constant since MGI's previous research on Europe, at about two-thirds of the United States in terms of diffusion and use of digital. The gap has two components. First, use of digital technologies in enterprises in Europe is 23 percent lower than in enterprises in the United States.[1] Second, a significant gap exists in use of digital technologies. For the same level of diffusion, European companies' share of investment in digital technologies was 28 percent lower than that of their US counterparts, and they hired 18 percent fewer full-time-equivalent (FTE) employees devoted to digitisation in the total workforce.[2] Although traditional incumbents in the United States generate 38 percent of sales through digital technologies, the share in Europe is 24 percent.

Industry digitisation still favours traditional incumbents in Europe, with 89 percent of total revenue still accruing to them compared with 86 percent in the United States by 2017. In Europe, new startups or players from adjacent sectors have seized 11 percent of revenue to date, but pure startup attackers have only 4 percent of total European corporate revenue—far lower than the share commanded by those companies in the United States, at about 7 percent (Exhibit 3).

We have tried to explain the gap in terms of digital intensity between US and European incumbent companies by deploying a battery of statistical analyses.[3] Three factors stand out. First, the intensity of cannibalisation is slightly higher in Europe (10 percent higher in sales share lost for European companies). Second, new attackers have yet to make the same inroads in industries as have those in the United States (remember that a large portion of digital native companies started first in the United States and rolled out only thereafter in Europe). Third, industry mix plays a role.

1 The technology set is composed of traditional web access, mobile internet, cloud, and big data.

2 The sample is based on 350 firms in the United States and the top five Western European economies.

3 The analyses were based on looking for correlates with the digital share of incumbent revenue by industry (10 industries) and by country (15 European countries, the United States, China, India, and Australia).

In the provision of AI, Europe attracted only 11 percent of global venture capital and corporate funding in 2016, with 50 percent of total funds devoted to US companies and the balance going to Asia (mostly China).[27] Two years later—in 2018—Europe may not have increased its share, according to data from CB Insights. China is now attracting almost 50 percent of global investment in AI startups, ahead of the United States, which has so far attracted 38 percent of total funding.

Europe could possibly deliver its fair share of AI startups, but they may lack scalability and success.[28] Only four European companies are in the top 100 global AI startups: Onfido and Tractable in the United Kingdom, Shift Technology in France, and Sherpa in Spain.[29]

27 *Artificial intelligence: The next digital frontier?* McKinsey Global Institute, June 2017.

28 The European Commission published a report in 2018 that used machine learning techniques to scope the volume of AI startups. The report concluded that European startups account for roughly the same share of GDP as their counterparts in the United States. If determining the level of startups is based on entrepreneurial activity, a better comparison would be based on population; using that measurement, Europe lags behind the United States. Even if the comparison is made by normalising GDP, Europe's standing is inflated by the strong position of the United Kingdom, but continental Europe lags behind the United States. See European Commission, *Artificial intelligence: A European perspective,* European Commission, December 2018.

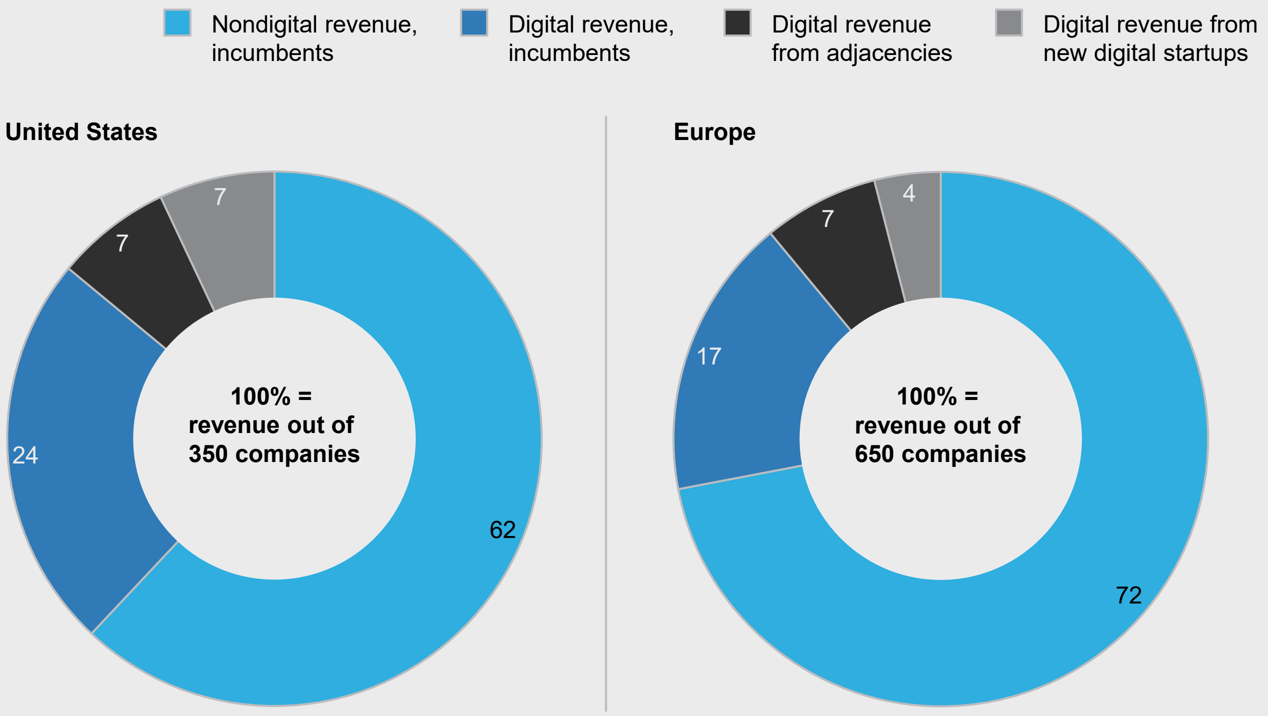
29 *AI 100: The artificial intelligence startups redefining industries,* CB Insights, December 12, 2017.

The largest companies in Europe are industrial companies that have lower digitisation, whereas in the United States the largest companies are well represented in the high-tech sector with high digitisation. Those three factors explain only 30 percent of the difference in performance; we therefore conclude that a large part (70 percent) of the digital gap between the United States and Europe is the ability to scale up digital transformation.

Exhibit 3

Europe's digitisation is less advanced than that of the United States.

Typical industry split
% of revenue



NOTE: Figures may not sum to 100% because of rounding.

SOURCE: McKinsey Digital Survey, 2017; McKinsey Global Institute analysis

By contrast, the United States still leads the world in the overall number of global AI startups and total equity deals. Three-quarters of the top 100 global AI startups tracked by CB Insights at the end of 2017 were in the United States. US companies also have a strong position in the semiconductor industry, which builds the AI chips necessary for big data handling and deep machine learning.

The EU has a long tradition of excellence in quantum computing research, but, as is the case with AI, it lacks scale. At the same time, China, for instance, is rapidly ramping up its research in this area with a new $10 billion national laboratory for quantum information science opening soon. European companies seem to fare comparatively well in robotics, too.[30] European industrial robotics companies command around one-third of the world market. In the smaller professional service robot market, European manufacturers produce 63 percent of nonmilitary robots. Japan and South Korea, however, still have the highest numbers of robots per FTE job. China's robot numbers are still low but growing fast, and the United States is now ahead of Europe on this metric. The market share of Europe is also

[30] *World Robotics Report 2016,* International Federation of Robotics, September 2016. Employment data are provided by Eurostat.

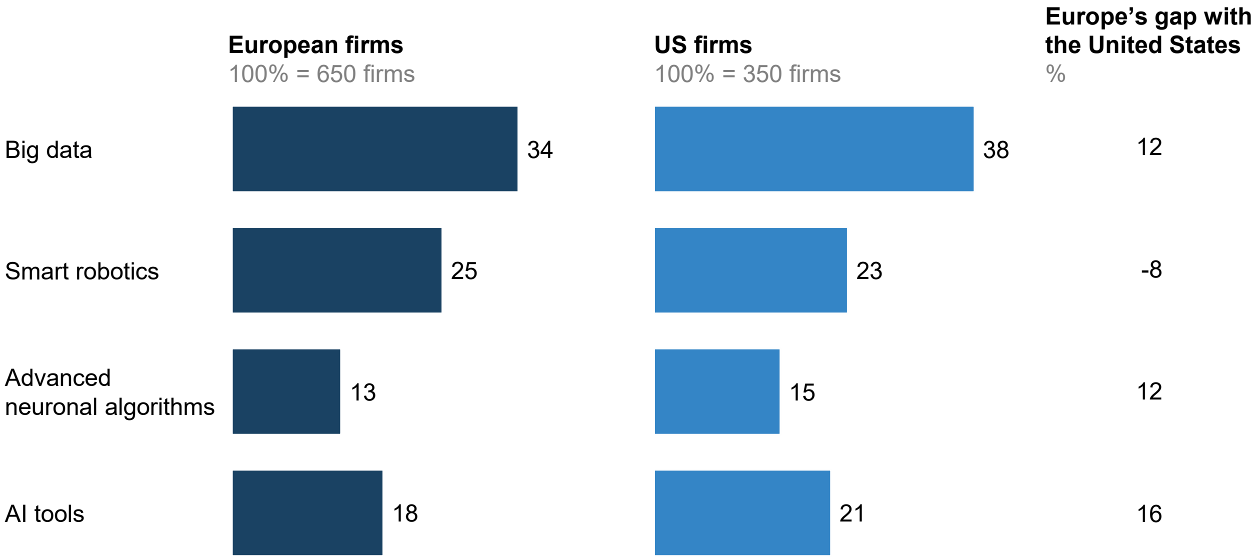
skewed toward a few countries with heavy use of robotics, including Belgium, Denmark, Germany, and Sweden. Robotics systems are not as prevalent in many other European countries, particularly in Eastern Europe. Europe is nevertheless showing considerable promise for the next generation of robotics, with particularly strong R&D in, for instance, cooperating robots and ambient intelligence; speech- and haptics-based human-machine interface; safety; actuation (without gears); control of arms and vehicles; and cybernetics.[31]

Available data on diffusion are scarce, but our blend of survey research demonstrates that European companies may lag behind their US counterparts in their adoption of big data architecture and of the advanced machine learning techniques that are the foundations of AI—with 12 percent less use than in the United States. A gap exists between Europe and the United States on the use of AI tools such as smart workflows, cognitive agents, and language processing—a 16 percent gap to date (Exhibit 4). Looking deeper at our data, the performance gap with the United States is especially important in the case of Southern Europe, which has a 22 percent gap with the United States, whereas Scandinavian countries, broadly, are on a par on use and performance with the United States, and the United Kingdom is not far behind.

Exhibit 4

Europe's AI diffusion lags behind that of the United States thus far, with the exception of smart robotics.

% of firms using AI at scale, 2017



SOURCE: McKinsey Digital Survey, 2017; McKinsey Global Institute analysis

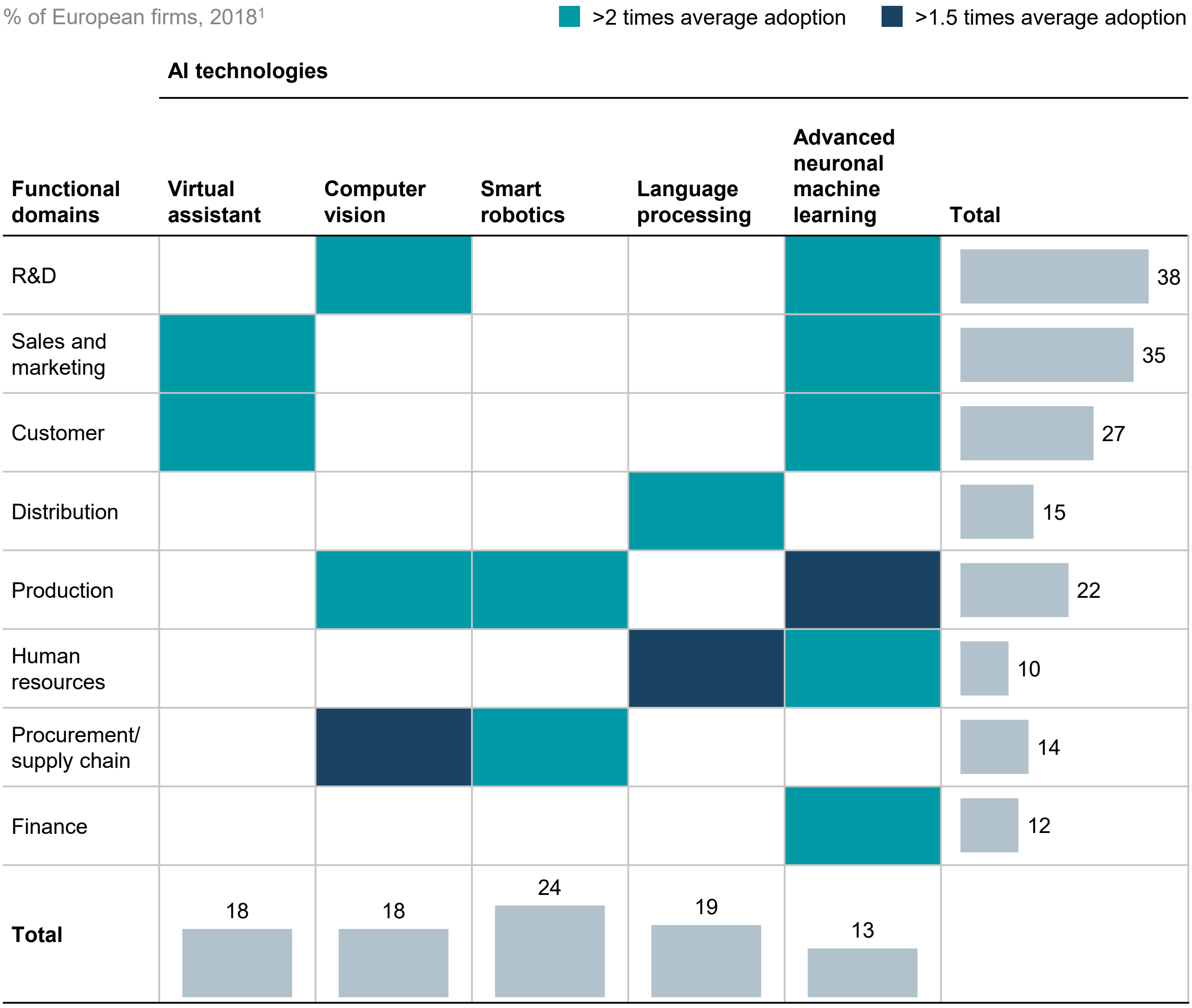
Moreover, European AI is yet to be deployed broadly in enterprises rather than in one or only a few functions. There is, of course, natural functional clustering of AI use cases by European companies. For instance, virtual assistance technologies are twice as prevalent in customer-facing functions as in other business functions. The same is true for smart robotics in supply chains and production. The most common areas of focus are marketing and sales, R&D, and supply-chain and production management. This finding is in line with MGI's global analysis, which found that AI's greatest potential value was in these key top-line and operational functions (Exhibit 5).[32]

[31] *Robotics in Europe—Why is robotics important?* The Partnership for Robotics in Europe (https://www.eu-robotics.net/sparc/about/robotics-in-europe/index.html).

[32] *Notes from the AI frontier: Insights from hundreds of use cases,* McKinsey Global Institute, April 2018.

Exhibit 5

European AI focuses on robotics and language processing.



1 Share of use case; use case is either for a single function or across the entire enterprise.

SOURCE: European Business Summit Members Survey, 2018; McKinsey Digital Survey 2018; McKinsey Global Institute analysis

A strong "power curve" is present, however, among European firms with only a relatively small subset of companies that already have significant breadth in their adoption and absorption of AI technologies—so-called full adopters, or front-runners—and a long tail of companies that are focusing only on a rather narrow set of AI and automation technologies for a limited range of corporate functions.[33]

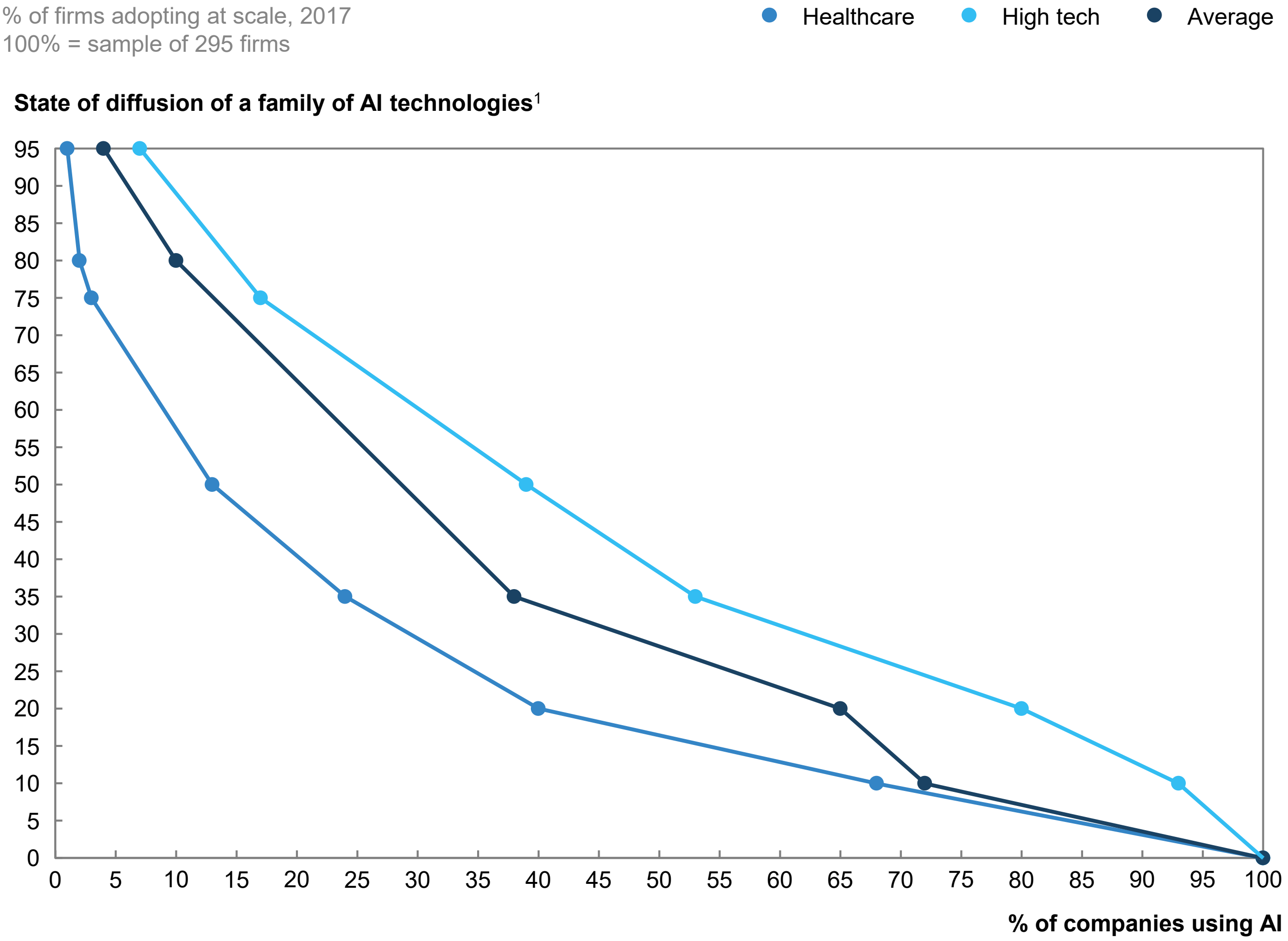
[33] In this paper, we use the terms "adoption", "diffusion", and "absorption." We define adoption as investment in a technology, diffusion as how adoption spreads—the process by which an innovation is communicated over time among the participants in a social system, and absorption as how technology is used within a firm. "Full absorption" is when a company uses the adopted technology for all operational purposes across its broad workflow system. These definitions align with those in academic literature. See, for instance, Tomaž Turk and Peter Trkman, "Bass model estimates for broadband diffusion in European countries", *Technological Forecasting and Social Change,* 2012, Volume 79, Issue 1; David H. Wong et al., "Predicting the diffusion pattern of internet-based communication applications using bass model parameter estimates for email", *Journal of Internet Business,* 2011, Issue 9; and Kenneth L. Kraemer, Sean Xu, and Kevin Zhuk, "The process of innovation assimilation by firms in different countries: A technology diffusion perspective on e-business", *Management Science,* October 1, 2006.

Some manufacturers may add smart robots to the shop floor, for example, but they have not achieved full adoption until they are using AI technologies from end to end, including in their purchasing, logistics, distribution, and sales functions. Only 5 percent of European AI adopters (compared with about 8 percent in the United States) are using these tools in about 90 percent of their entire organisations. Seven of ten companies, however, are capturing 10 percent of full potential use. In the most advanced industry—high tech—93 percent of adopters are capturing AI for 10 percent of its potential use, but still only 17 percent of European companies (compared with about 22 percent in the United States) are using AI technologies at 75 percent of potential. At the other extreme, only 2 percent of European firms in healthcare systems and services are using those technologies at 80 percent of potential (Exhibit 6).

Exhibit 6

Only a few European companies have fully absorbed all AI technologies.

% of firms adopting at scale, 2017
100% = sample of 295 firms



1 Index = 100 when a company invests in the entire family of AI technologies (computer vision, language processing, robotics, virtual assistant, and advanced machine learning) and uses it across the entire enterprise.

SOURCE: McKinsey Digital Survey, 2018; McKinsey Global Institute analysis

2. AI MAY SCALE UP IN A FAST-PACED GAME OF COMPETITION, INNOVATION, AND NEW SKILLS ACQUISITION

Typically, general-purpose technologies such as AI boost an economy's performance via the interplay of three channels. First, sectors producing new technologies benefit from a fast pace of technological progress. Second, technological progress accelerates the capital-deepening process in the new technology-using industries, leading to an increase in capital intensity and therefore in labour productivity. Third, the widespread use of technologies may lead to spillovers (for example, network effects) that boost global productivity.

How those channels are activated and play out will determine the extent of the productivity boost that comes from AI and the competitive advantage of economies. As noted, a paucity of data is available on how channels will play out, and we have therefore used the common findings of three surveys to uncover the possible dynamics for AI. We, in fact, find three critical components: competition (more than thought), innovation (more varied than automation alone), and new skills (more cognitive and social where demand is already in excess supply in Europe).

AI IS PERCEIVED AS A COMPETITIVE PLAY

Before the advent of AI, digital technologies favoured new business models from attackers, disrupted incumbent firms, and intensified competition. When digital natives enter a market, they may boost the size of the industry, but their main effect is to capture market share from incumbents. Current levels of digitisation have already taken out, on average, up to six points of annual revenue growth from incumbents in Europe.[34] The effects of new digital entrants in a given industry often spiral, triggering even more competition among incumbents, with those that do not adopt digital technologies bearing the brunt. Companies that initiate digital disruptions often are rewarded with disproportionate gains, and fast-following companies that execute well also tend to come out ahead. But for the bottom quartile of companies, profit and revenue growth come under severe pressure.

This pattern is likely to repeat itself, but with more intensity, as AI technologies are adopted, according to our surveys. When European companies that have not yet invested in AI were asked whether they see some competitive risks from both AI-native firms and early AI adopters among incumbents, nonadopters perceived there to be equal risk from both types of companies. For example, a majority (53 to 57 percent) of nonadopters believed that both can engage in aggressive taking of market share from competitors (Exhibit 7).

Those perceptions can be justified. In ICT, in which competition is notably intense, the development of AI leads to competition from new business models developed as a way to gain new temporary competitive advantage.[35] Germany-based software company SAP, for example, has been building machine learning technology into all its software and is moving into platform-based competition with other major business-to-business software providers, such as US-based Oracle and Salesforce.com. We also find in our survey that taking market share from competitors is the primary objective for 15 percent of European companies investing in AI (slightly below the share of Asian and North American firms, at just over 20 percent). This intent of taking market share is lower in sectors such as construction, travel and transport, and manufacturing—sectors that are also less digitised than the average sector. Telecoms, finance, and retailing, all sectors in which AI has already made major inroads, display a higher degree of competitive intent—in retail through sales recommendations, predictive inventory management, smart robotics, and fulfilment, for instance.

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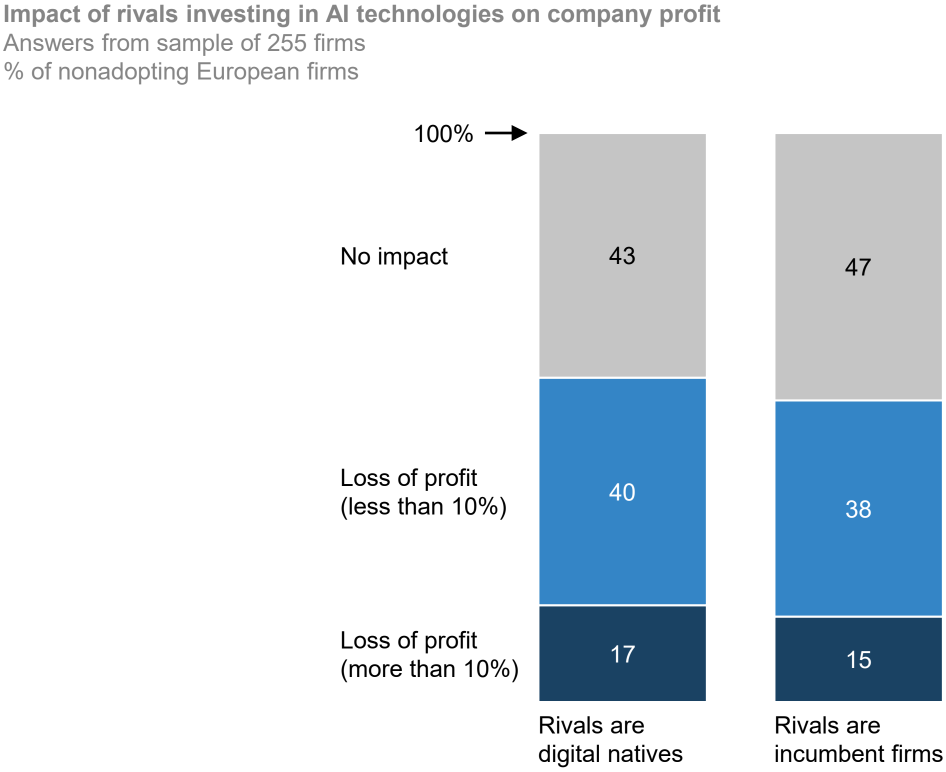
[34] Nicolas van Zeebroeck and Jacques Bughin, "The best response to digital disruption", *MIT Sloan Management Review,* April 2017.

[35] Chi-Hyon Lee et al., "Complementarity-based hypercompetition in the software industry: Theory and empirical test, 1990–2002", *Strategic Management Journal,* Volume 31, Issue 13, October 27, 2010.

Exhibit 7

AI adoption may lead to significant taking of market share.



NOTE: Figures may not sum to 100% because of rounding.

SOURCE: European Business Summit Members Survey, 2018; McKinsey Global Institute analysis

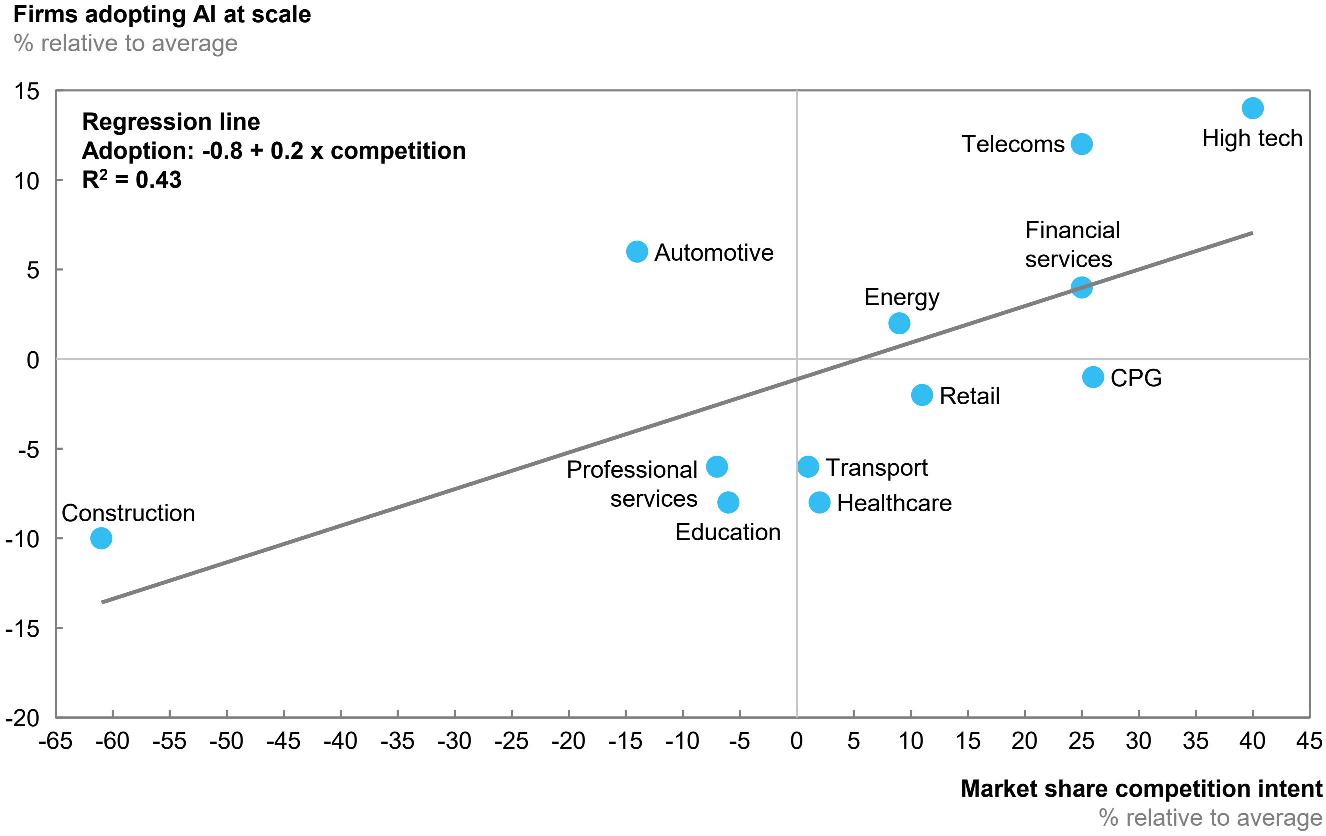
Incumbents mastering digital technology and adding AI have also been able to turbocharge their competitive value proposition (Exhibit 8). Our survey clearly shows that digitally savvy European companies are 15 to 25 percent more likely to use AI (the range reflects differences by sector). Consider the case of Kura, one of Japan's many high-tech sushi restaurants. It has been serving sushi over rice balls on an automated conveyor belt for a decade, with much better labour productivity than traditional sushi restaurants. The idea at that time was to offer sushi to the young population in Japan at lower prices than traditional sushi. Now Kura is using AI to further enhance its competitive edge.[36] It is automating service via advanced robotics, radically reducing the labour needs of each of its locations, and combining its belt model with a microchip embedded in each food container to collect data and to help predict just-in-time demand for sushi, helping to ensure better matching of food to customer demand via deep learning algorithms. AI is not only helping to generate even higher profitability but also enabling the company to expand its franchise and further improve its retail prices for consumers.[37]

[36] Kura is only one of many food chains eagerly investing in AI. See Kumba Sennaar, *Examples of AI in restaurants and food services,* Emerj (formerly TechEmergence), September 18, 2018; and Kana Inagaki, "Japan's robot chefs aim to show how far automation can go", *Financial Times,* February 1, 2017.

[37] An early article about the first automation wave was Hiroko Tabuchi, "For sushi chain, conveyor belts carry profit", *New York Times,* December 30, 2010. On the recent acceleration via AI, see Brian Rogers, *Help NOT wanted! Is it possible to have a fully autonomous restaurant?* Tech 2025, April 6, 2017.

Exhibit 8

Company intentions to use AI for competitive purposes correlate with industry diffusion.



SOURCE: VivaTech survey, 2017; McKinsey Digital Survey, 2018; McKinsey Global Institute analysis

AI'S POTENTIAL TO DELIVER REVENUE GROWTH THROUGH INNOVATIONS RATHER THAN EFFICIENCY ALONE IS MOTIVATING EUROPEAN ADOPTERS

For all of AI's potential, most of the debate surrounding it focuses on its effect on efficiency—in particular, whether it will eliminate large numbers of jobs. Our various surveys consistently find, however, that companies are equally—if not more frequently—motivated by the pursuit of capital productivity and the efficiency of nonlabour inputs (Exhibit 9).

Further, companies say that they are also keen to adopt AI for revenue growth. About 30 percent of European adopters report that they are using AI with an eye to revenue expansion, whether through extending into new markets or gaining market share. Europe is not an exception in terms of the mix of motivations for AI adoption; survey responses closely align with those of Asian and North American companies.

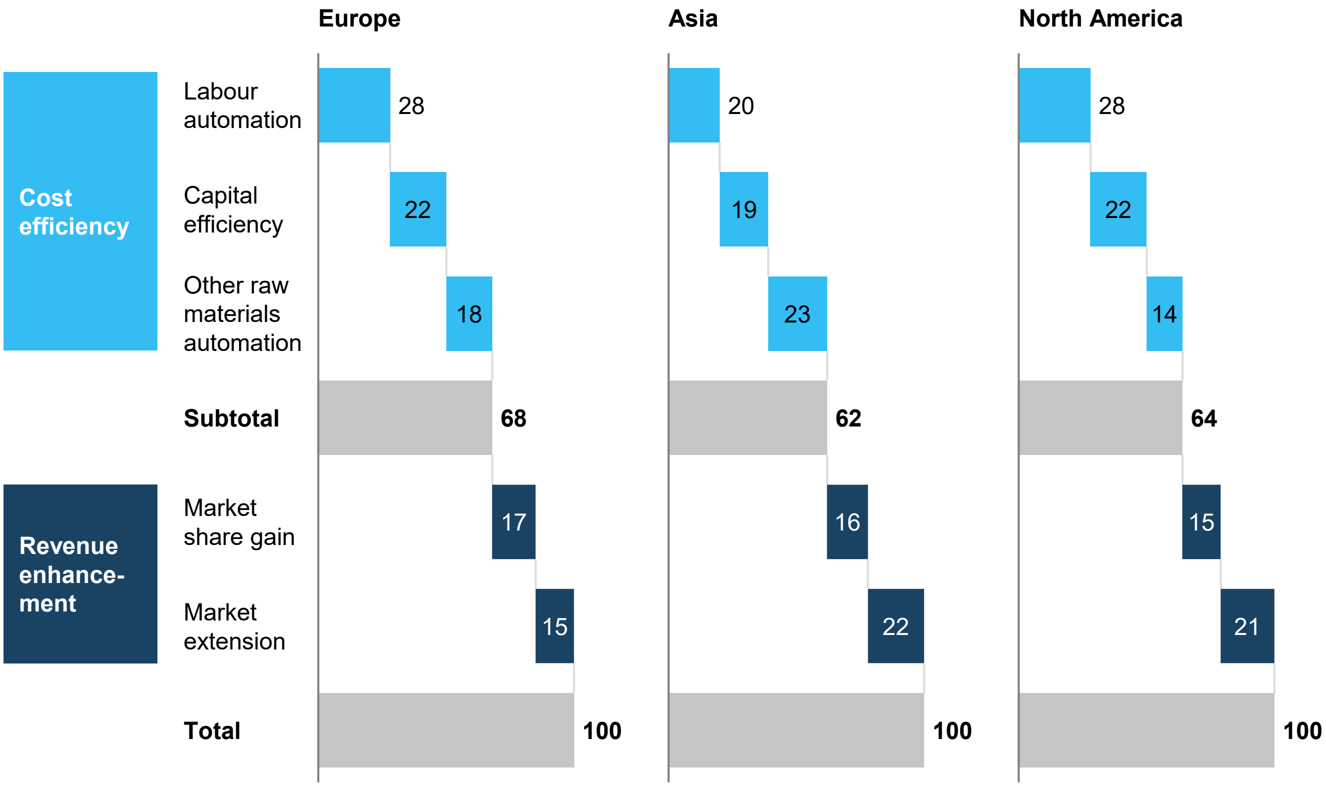
Companies with less experience in AI tend to focus on its ability to help cut costs, but the more that companies use and become familiar with AI, the more potential for growth they see in it.[38] Companies in business-to-consumer sectors are most likely to aim for market expansion. Early European AI adopters in retail cited AI's potential for fuelling business growth almost twice as often as its potential for cutting costs. They use AI to gain insights that they can use to boost sales—for example, reviewing shoppers' habits and suggesting personalised promotions and tailored displays. They report sales growth of 1 to 5 percent in traditional stores but even more dramatic gains of as much as 30 percent in online sales through the use of personalisation and AI-enabled dynamic pricing.

[38] Jacques Bughin and Eric Hazan, "Five management strategies for getting the most from AI", *MIT Sloan Management Review,* September 2017.

Exhibit 9

AI adoption is not exclusively driven by labour efficiency.

Main objective of investing in AI
% of firms adopting AI technologies, 2017



NOTE: Figures may not sum to 100% because of rounding.

SOURCE: European Business Summit Members Survey, 2018; VivaTech survey, 2017; McKinsey Global Institute analysis

SKILLS AND ASSETS MATTER

Why are some companies absorbing AI technologies while most others are not? Among the factors that stand out are their existing digital tools and capabilities and whether their workforce has the right skills to interact with AI and machines.

Only 23 percent of European firms report that AI diffusion is independent of both previous digital technologies and the capabilities required to operate with those digital technologies; 64 percent report that AI adoption must be tied to digital capabilities, and 58 percent to digital tools (Exhibit 10).

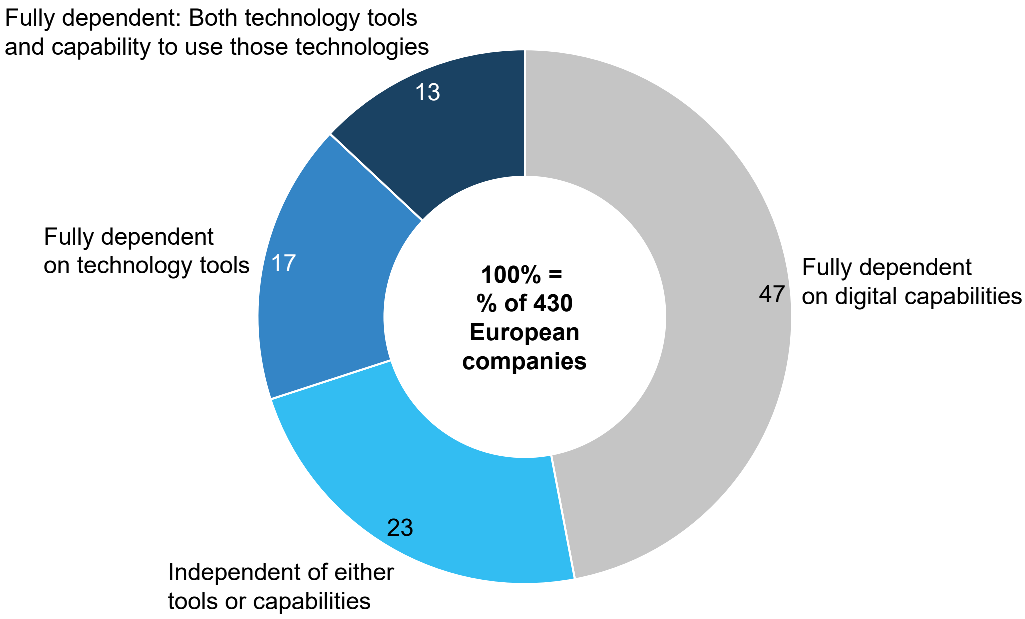
That degree of influence translates into a strong dependence on previous digital actions in the pattern of AI diffusion. European companies that have fully absorbed the previous set of digital technologies are 30 percent more likely to be first movers in AI adoption and use. For those companies, AI is another step forward (albeit a large one) in an ongoing journey rather than a jolting change in direction. AI relies on a steady diet of data to train algorithms, so companies that are already capturing and analysing data systematically have the foundation they need.

In particular, European firms that have adopted big data and advanced analytics are much more likely to move forward into AI. More than two-thirds of the AI business use cases identified by MGI are extensions of existing analytical use cases. Traditional analytics and machine learning techniques continue to underpin a large percentage of the value creation potential in industries including insurance, pharmaceuticals and medical products, and telecommunications, with the potential of AI limited in certain contexts.[39]

Exhibit 10

AI diffusion relies on the technical and organisational capabilities of previous adoption of digital technology.

How much does AI depend on previous adoption of early digital technologies?
%



NOTE: Figures may not sum to 100% because of rounding.

SOURCE: European Business Summit Members Survey, 2018; McKinsey Global Institute analysis

The largest influence of AI adoption, however, is the development of complementary human skills as AI technology advances. In fact, respondents to our surveys report that the two biggest barriers to AI adoption in European companies are linked to having the right workforce in place. The first barrier relates to the ability to use ICT tools in work. Those skills are not evenly distributed in Europe. Countries such as Finland have a more abundant supply of workers with the skills that are likely to be in demand than, say, Italy and Spain.[40] The second barrier relates to companies' need for skills to provide new AI applications and services, such as AI coding and analytic expertise. This is another challenge for Europe. One recent study that examined the German labour market found that job openings for engineers, technicians, and software analysts were particularly difficult to fill, and that the share of employers with difficult-to-fill jobs has increased in recent years (Exhibit 11).[41]

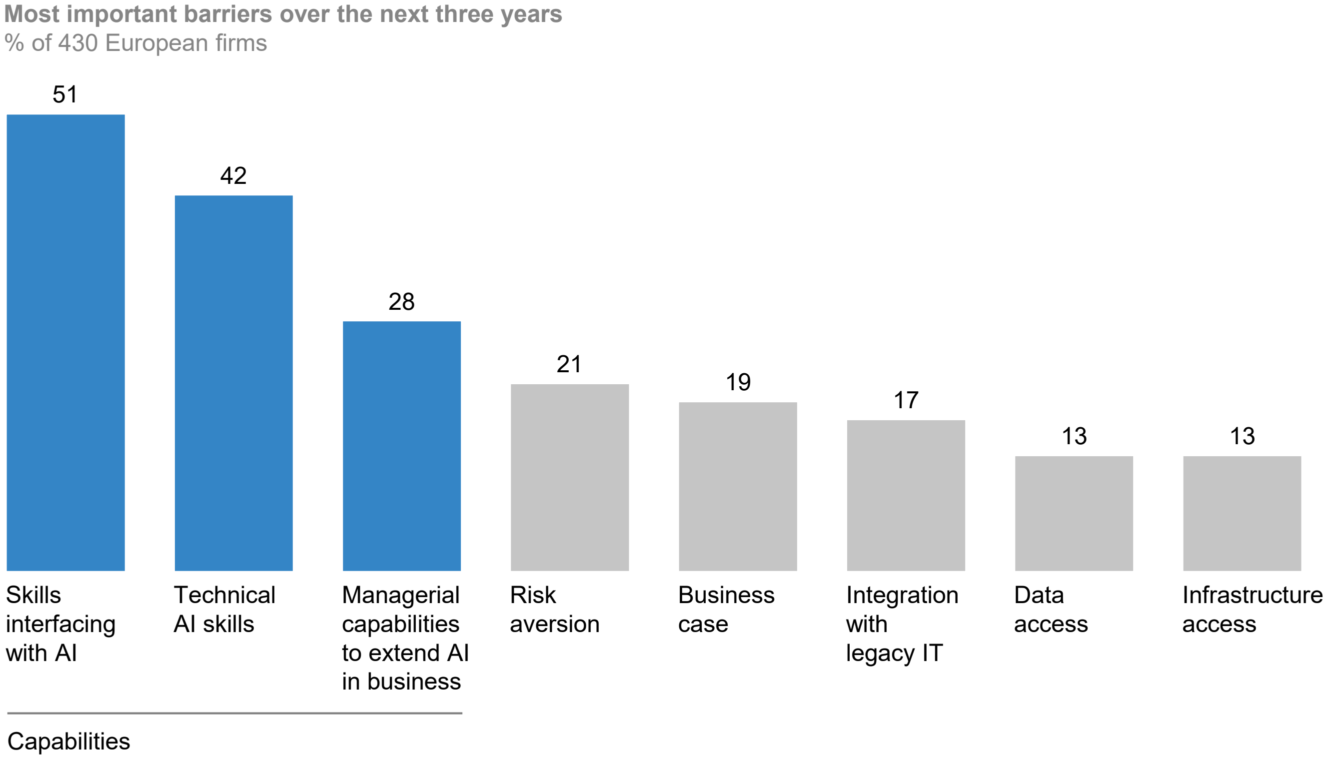
[39] *Notes from the AI frontier: Insights from hundreds of use cases,* McKinsey Global Institute, April 2018.

[40] John W. Miller and Michael C. McKenna, *World Literacy: How Countries Rank and Why It Matters,* New York, NY: Routledge, 2016.

[41] Ulrich Walwei, *Digitalization and structural labor market problems: The case of Germany,* International Labor Office (ILO) research paper number 17, September 2016.

Exhibit 11

The skills needed to boost corporate AI adoption in Europe are in short supply.



SOURCE: European Business Summit Members Survey, 2018; McKinsey Global Institute analysis

THE DRIVERS OF AI ADOPTION HAVE THREE MAJOR IMPLICATIONS FOR EUROPEAN BUSINESS AND SOCIETY

The three drivers of AI adoption highlight three fundamental implications for the future that could affect industries and countries across Europe. First, the competitive edge associated with AI and the fear of being disrupted may lead to a competitive race—such a race has already begun between China and the United States in the internet sector.[42] The various surveys we used lead us to estimate that competition among firms may account for 50 percent of European corporates' decision to adopt AI by 2030.

Second, AI will be used for new business models, products and services, and skills, which suggests a large transformation of most jobs, including an emerging talent war for AI and digital skills coupled with creative skills. Such a talent war is already visible today, with, among others, China trying to overcome its main weakness in fundamental AI research by recruiting massively in the United States and elsewhere.[43]

Third, AI may have substantial positive implications for economic growth and productivity but may feature winner-take-most dynamics in many industries, as companies are likely to adopt at very different paces and therefore have different abilities to take advantage of the opportunities afforded by AI. Multiple recent studies have found that corporate competition is increasingly determined by which player makes the best

[42] Louise Lucas and Richard Waters, "China and US compete to dominate big data", *Financial Times,* May 1, 2018.

[43] See *Lawfare,* "Beyond CFIUS: The strategic challenge of China's rise in artificial intelligence", blog entry by Elsa Kania, June 20, 2017, https://www.lawfareblog.com/beyond-cfius-strategic-challenge-chinas-rise-artificial-intelligence; and Will Knight, "China's awakening", *MIT Technology Review,* October 10, 2017.

use of technology.[44] Some firms may use AI to gain competitive advantage, whereas many others could fall victim to disruption. Our average case estimate suggests that the 10 percent of European companies that are the most extensive users of AI to date are likely to grow three times faster than the average firm over the next 15 years. Those companies are likely to achieve that growth with lower full-time equivalents (FTEs) per unit of revenue, increasing labour productivity more than will other companies. That dispersion in productivity gains in favour of front-runners has similar characteristics to the recent phenomenon of superstar firms.[45]

If we take all those elements together, it means that the European playing field and its success in AI will likely be guided by how fast it plays, how aggressively it assembles the right mix of skills, and how many champions it can create. We have quantified those effects through our calibrated model of AI diffusion for each of the EU-28 countries (see Box 1 and the appendix for more detail) and examined key sensitivities.

Implication 1. AI diffusion in Europe is likely to be a competitive race

It takes time for a new technology to be widely adopted, let alone to create significant change across an economy. The Solow Paradox underscores the irony of seeing new technologies "everywhere but in the productivity statistics."[46] That phenomenon has occurred throughout history; general-purpose technologies such as steam or electricity took almost three decades to achieve widespread adoption and, ultimately, productivity gains. Today, digital technologies spread faster, yet full diffusion still takes decades.[47] The previous generation of digital technologies took about 35 years to affect 80 percent of total economic activity in Europe.[48] In general, the process of diffusion resembles an S-curve. Internet access diffusion took seven years to accelerate in Europe, then another five years to hit a peak diffusion rate.[49]

Many factors should affect the pace of diffusion of AI technologies. Regarding the macroeconomic context, for instance, companies' incentives to automate will depend on the relationship between wages and the cost of technology. Regarding more microeconomic factors, the characteristics that emerge from our surveys suggest a large competitive risk if companies delay their adoption of AI. MGI's micro-to-macro model aggregates the estimated adoption and absorption of AI by global corporations.[50] We find that the microeconomic factors are the most important factors likely shaping European corporate adoption and absorption of AI. Our econometric findings indicate that a corporation will more likely than not adopt AI right away if its main rivals do. Contrast that with the fact that only one company out of eight is likely to adopt AI right away even if they perceive a business case for AI.

This paper applies the global econometric model developed in our global research effort to all European countries.[51] Because AI is a developing field, we have updated the model to integrate the possibility that part of the competitive race is the result of large uncertainty

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44 See, for example, Mordecai Kurz, *On the formation of capital and wealth: IT, monopoly power, and rising inequality,* Stanford Institute for Economic Policy Research working paper number 17-016, June 2017.

45 *Superstars: The dynamics of firms, sectors, and cities leading the global economy,* McKinsey Global Institute, October 2018.

46 Jack E. Triplett, "The Solow Productivity Paradox: What do computers do to productivity?" *The Canadian Journal of Economics,* Volume 32, Number 2, April 1999.

47 Sanjev Dewan, Dale Ganley, and Kenneth L. Kraemer, "Complementarities in the diffusion of personal computers and the internet: Implications for the global digital divide", *Information Systems Research,* Volume 21, Issue 4, published online December 2010.

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

49 Tomaž Turk and Peter Trkman, "Bass model estimates for broadband diffusion in European countries", *Technological Forecasting and Social Change,* Volume 79, Issue 1, January 2012.

50 *How AI may impact the world economy,* McKinsey Global Institute, July 2018.

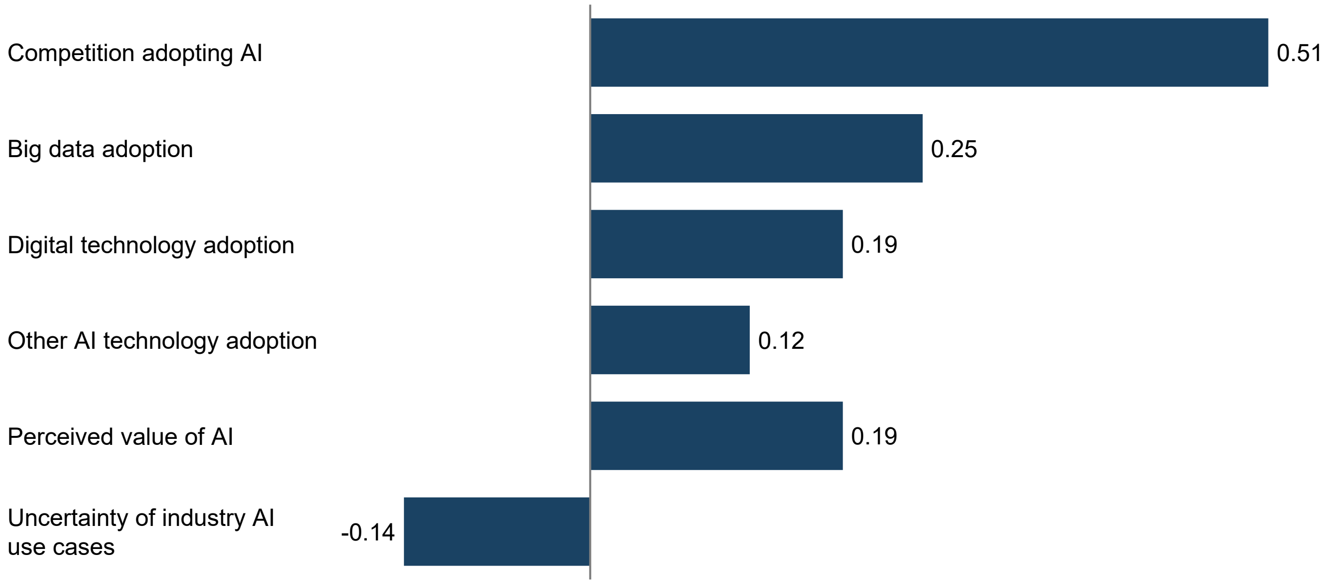
51 *Notes from the AI frontier: Modeling the impact of AI on the world economy,* McKinsey Global Institute, September 2018.

about how AI might unfold.[52] If material, uncertainty could boost the herd behaviour of firms in terms of their AI adoption, but it does not guarantee that adoption will be sustained; in some cases, market potential is not warranted, and a bubble may appear.[53] In addition, in this research we have run the model for each family of AI technology, namely deep machine learning, natural language, video recognition, virtual assistants, and smart robotics. We find that, on average, the largest motivation for a European company to adopt AI is competition—it has a 51 percent probability of adopting an AI technology if its rivals have done so (Exhibit 12).[54]

Exhibit 12

Competition is the largest driver of European AI adoption.

Estimated probability of adopting a specific AI technology[1]



1 Includes piloting AI technology. The coefficient is an average of the five AI technologies analysed (computer vision, machine learning, language processing, smart robotics, and virtual assistants) weighted by the current adoption rate by technology. All drivers are measured relative to competition.

SOURCE: McKinsey Digital Survey, 2017; McKinsey Global Institute analysis

Extrapolating from those econometrics, we can infer that, everything being equal, slightly more than 72 percent of European companies could be toying with at least one of the AI technologies throughout their organisations by 2030. Beyond those companies only piloting AI (17 percent), 55 percent will be rolling out at least one AI technology, whereas two-thirds of those—or 35 percent of corporations—will have deployed the full range of AI technologies to operate at enterprise level, up from barely 3 percent of European firms today. The prospect of a continued and prolonged competitive race for Europe clearly—and importantly—implies that, should European companies be insensitive to competitive pressure, the diffusion of AI by 2030 could be half of what is estimated.

[52] Literature on strategy recognises that when significant uncertainty exists, firms are better off replicating the moves of their rivals, thereby drawing on lessons learned. By including uncertainty as an additional measure in our econometric model, we control for herd-like behaviour that could create a bubble (and the bursting of that bubble). In addition, uncertainty has a direct negative effect on the propensity to invest.

[53] Our survey asks explicitly how executives feel about their perception of the AI business case for their company. Perceptions can range from full certainty of that business case to large uncertainty about how the business case will unfold. We incorporated those perceptions as a specific control variable in the decision to adopt AI.

[54] The results are based on profit regressions for each firm adopting or not adopting AI, averaged across the five technologies surveyed.

Implication 2. AI's biggest outcome may be shifting demand for skills

Job and skills are likely to change in Europe as a result of AI. Automating tasks with the specific goal of reducing the workforce is only one of many reasons a company might adopt AI. Indeed, it is the primary motivation for less than 30 percent of European companies.

We relied on recent research from MGI that looked at automation through the lens of individual tasks and work activities rather than occupations. The research found that tasks that could potentially be automated by adapting currently demonstrated technologies made up 150 billion hours worked yearly in Europe, which represents 45 percent of about 190 million current FTEs.[55] Based on the competitive-based diffusion of AI we have estimated by 2030 for Europe and the economic finding that jobs with more than 70 percent of tasks substitutable by automation could profitably be replaced by machines, between 20 million and 30 million (an average of 25 million) current FTE jobs may be changed by 2030 in Europe because of AI. That would amount to about 0.9 percent of current FTE employment per year.[56] Such a rate of employment change would be double the one observed in the first decade of this century as a result of European businesses adopting technologies that perform routine-based tasks.[57] Such a depletion rate has been seen before—focused on specific technologies in which competition has been intense, such as CAD-enabled robotics in the early 1990s where Swedish and German manufacturing companies reduced employment by 2 percent a year.[58] That reduction in employment was confined to manufacturing, however.

The speed and extent of these job challenges are likely to vary by country, depending on both automation potential and diffusion speed. In countries with lower digitisation, less competition, and less attractive returns for job automation, such as Romania or Bulgaria, only about half the rate of job change could occur by 2030.

In the range of 20 million to 30 million FTE jobs could be displaced by 2030 across EU-28 countries, and we expect that 90 percent, or 80 million, of the remaining jobs may have some tasks adjusted by AI by 2030. Those tasks could make up in the range of 25 to 30 percent of current time worked, which implies that as many FTE—we calculate around 20 million to 25 million, with an average of 22 million—could be new tasks affected by technology that will require new kinds of skills. Those estimates are in line with other MGI research that has highlighted a potential shift of 40 billion hours in Europe toward more social, technological, and higher cognitive skills by 2030.[59]

A great deal of evidence indicates that the skills mix is changing. In the late 20th century, the advent of computers and information technology increased the demand for workers with

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55 We use the Cedefop (Centre Européen pour le Développement de la Formation Professionnelle) figures of 220 million people employed, corrected for the 19 percent of people in the EU-20 who are part-time workers, according to Eurostat (http://ec.europa.eu/eurostat/statistics-explained/index.php/Employment_statistics#Part-time_work:_slight_decrease_in_2016). See *Harnessing automation for a future that works,* McKinsey Global Institute, January 2017.

56 This figure is calculated as 45 percent of automation times 55 percent of jobs at risk times 190 million, which equals 47 million FTEs. By 2030, about 35 percent of FTEs will be fully diffused with AI, and an additional 20 percent will be partly diffused, as companies adopt some, but not all, AI technologies. By 2030, our analysis therefore indicates that 53 percent of 44 million existing jobs—23 million—could be at risk. These estimates are in line with other MGI research—in Germany, for instance. See *Jobs lost, jobs gained: Workforce transitions in a time of automation,* McKinsey Global Institute, December 2017. The difference here is that we do not take the average external benchmark for AI diffusion but model it explicitly. Further, we compute occupations and not FTE so that we can compare the figures with figures for occupations affected by automation and digital technologies in early academic research.

57 Terry Gregory, Anna Salomons, and Ulrich Zierahn, *Racing with or against the machine? Evidence from Europe,* ZEW discussion paper number 16-053, 2016.

58 Steffen Kinkel, Christoph Zanker, and Angela Jäger, *The effects of robot use in European manufacturing companies on production offshoring outside the EU,* June 2015.

59 *Skill shift: Automation and the future of the workforce,* McKinsey Global Institute, May 2018.

higher-education-level skills, accelerating demand for such workers by roughly 50 percent.[60] In the early days of automation of the car industry, General Motors rebuilt an assembly plant with state-of-the-art robots and industrial automation.[61] That change increased the demand for higher skills, with 40 percent more workers reporting that problem-solving skills had become very important.

Just as digitisation brought new demand for skills associated with digital marketing and big data analysis, so today and in the near future, a different skills mix is likely to be needed to complement AI and robotics. Those technologies excel at accomplishing explicit, codifiable tasks that are today characterised as being routine.[62] Many routine tasks in the past have been associated with activities that attract medium wages; they include, for instance, mathematical calculations in simple bookkeeping and repetitive physical operation on assembly lines.[63] AI and robotics will require new skills in robotic maintenance and engineers who specialise in AI or the Internet of Things.

The survey conducted by MGI for VivaTech explicitly asked how AI-related technologies had affected employment or would affect it in future.[64] Fine-tuning that survey for European firms, the survey indicates that changes in skills are likely to be as high as changes in employment: 29 percent of companies reported a decline in employment as a result of AI, the same share of respondents that reported an increase. That aggregate pattern holds at the industry level except in manufacturing, construction, and retail, in which respondents tend to have a negative view of employment prospects linked to AI.[65] Sectors that are more advanced in AI have a higher share of respondents who anticipate a ramping up of their demand for labour and a reallocation of labour. About half of European telecoms, media, and ICT companies surveyed said that they would be increasing employment or reallocating labour as a consequence of adopting AI-related technologies.

Homing in on the detail of different skills categories, the survey indicates that between 25 and 45 percent of respondents reported a change in the skills mix commensurate with, or even larger than, expected employment change. The largest share of firms (28 percent) reported a decline in demand for basic literacy and basic numerical skills; 40 percent of European firms also anticipated higher demand for advanced data and IT skills. In summary, AI may continue to induce skills-biased technological change in the employment mix, as happened in the recent past (Exhibit 13).[66]

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60 Michael J. Handel, *Dynamics of occupational change: implications for the occupational requirement surveys,* July 15, 2016.

61 Ruth Milkman and Cydney Pullman, "Technological change in an auto assembly plant: The impact on workers' tasks and skills", *Work and Occupations,* Volume 18, Issue 2, May 1, 1991.

62 David H. Autor, "Why are there still so many jobs? The history and future of workplace automation", *Journal of Economic Perspectives,* Volume 29, 2015.

63 Martin Goos, Alan Manning, and Anna Salomons, "Explaining job polarization: Routine-biased technological change and offshoring", *American Economic Review,* Volume 104, Number 8, August 2014.

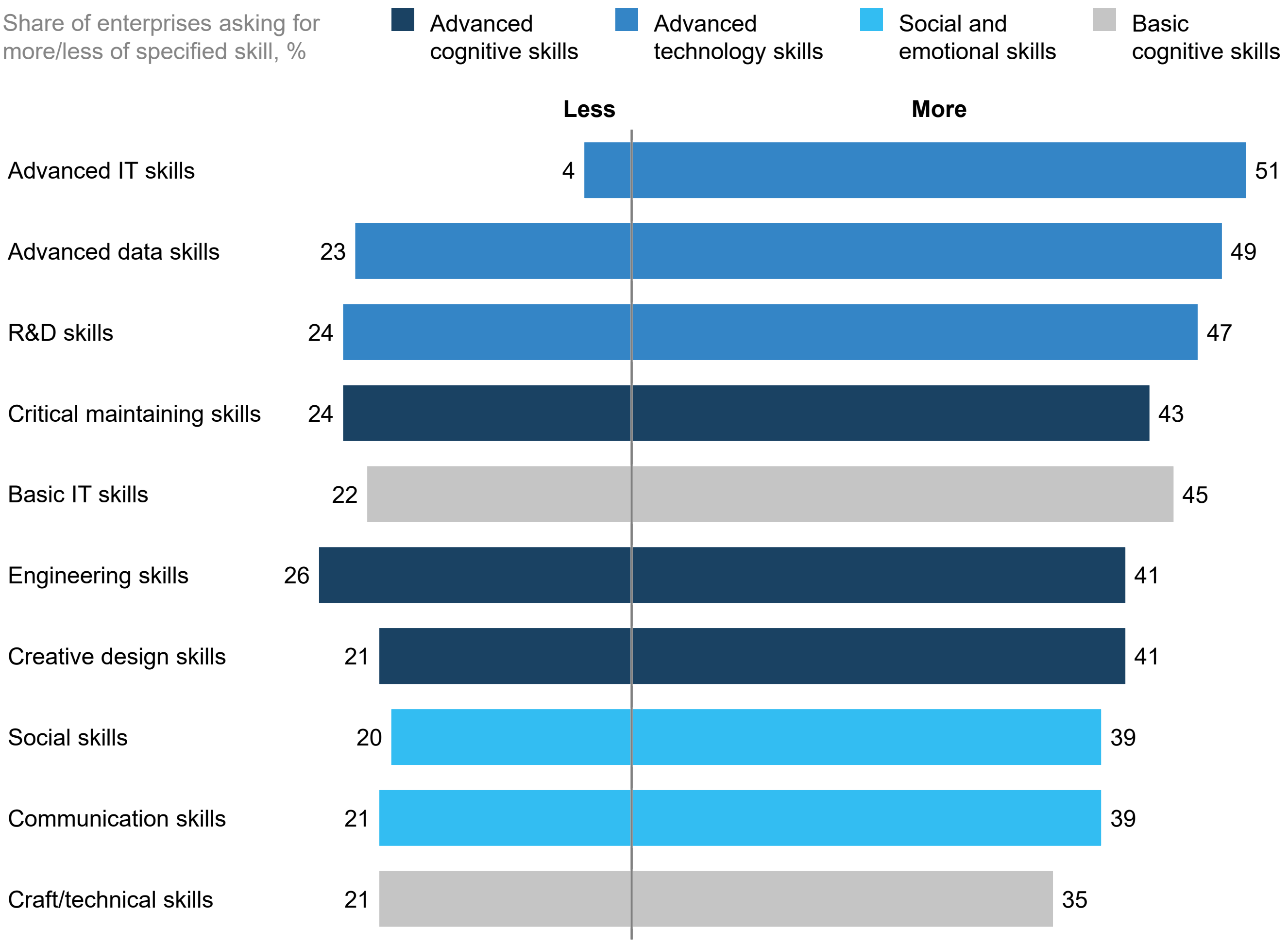
64 We are keen to understand the expectations of firms, as the current level of AI diffusion across all technologies is still relatively low.

65 Those sectors are also sectors with momentum challenges in Europe, possibly leading to an answer bias in which executives attribute employment decline to AI even though it may be due to other industry-specific sector challenges.

66 The same skill-biased tendency is also noticeable in econometric analysis that links occupations and tasks to the OECD Programme for the International Assessment of Adult Competencies (PIACC) skills database. See 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 Papers number 189, 2016.

Exhibit 13

Advanced skills for AI diffusion are in greatest demand from European firms.



SOURCE: VivaTech survey, 2017; McKinsey Global Institute analysis

Responding to such large demand shifts is not likely to be easy. European companies already have difficulty filling vacancies in areas that require high cognitive skills.[67] The same is also true for tech-related skills, such as those required for big data analytics or coding. In 2015, the European Commission predicted that as many as three-quarters of big data–related jobs would remain unfilled until 2020 because of excess demand for analytics skills.[68] MGI found that 26 percent of companies that adopt AI are concerned that they will not be able to obtain the skills necessary to fill their needs. The OECD computed likely frictions in high cognitive and technological skills (for example, mathematical skills) and more-physical skills (for example, process-knowledge skills).[69] Excess demand is already becoming the rule for the first type, especially in more digitally advanced countries, such as the Scandinavian countries, whereas excess supply is slowly building on the second type, except in France and Denmark (Exhibit 14).

[67] Daniela Ulicna and Sarah Fleury, *Using data for preventive and remedial measures to address early leaving,* Expert Workshop: The Role of VET in Reducing Early Leaving from VET, Thessaloniki, Greece, June 3–4, 2014 http://www.cedefop.europa.eu/en/publications-and-resources/presentations/findings-cedefop-study-0.

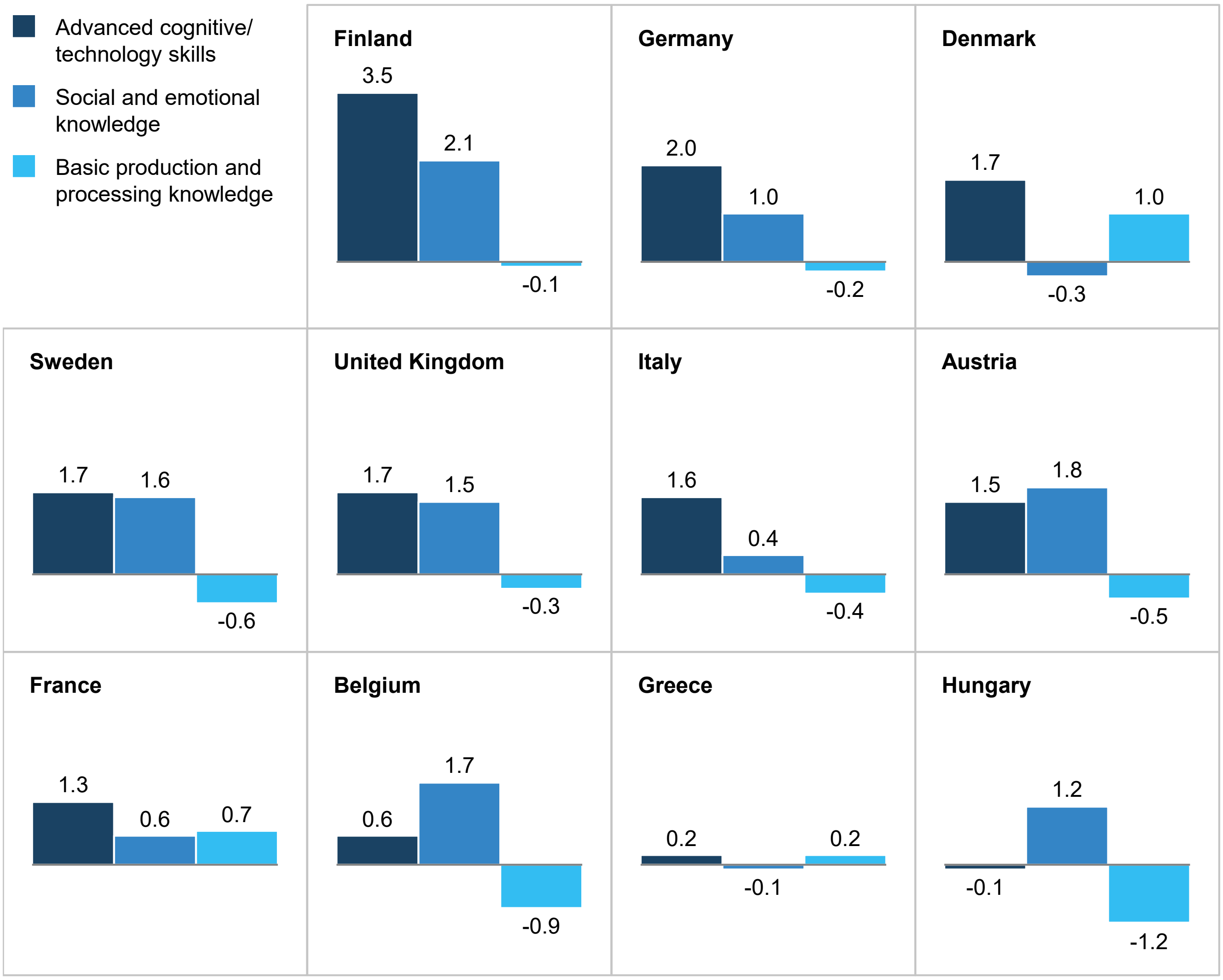
[68] *Big data analytics—An assessment of demand for labour and skills,* 2012–2017, European Commission, July 2, 2014.

[69] *Getting skills right,* OECD iLibrary, https://www.oecd-ilibrary.org/employment/financial-incentives-for-steering-education-and-training-acquisition_9789264272415-en.

Exhibit 14

Europe is already in short supply of new advanced skills.

Net demand, % (positive numbers imply skills shortage)



SOURCE: OECD skills database; McKinsey Global Institute analysis

Sweden is a good showcase for demonstrating how the skill shift may play out with respect to AI diffusion (Exhibit 15). Sweden is one of the most digitally advanced countries in Europe and is slightly ahead of others in diffusing AI. Employment in ICT and telecoms has increased, leading to a notable shift in skills toward higher cognitive skills from lower ones over the past two decades.[70]

Other research has looked at both changes of skills driven by corporate demand and changes induced by the evolution of skill supply, reflecting, for example, the evolution of cohorts and changes in education.[71] These were the three main conclusions:

1. Excess demand already exists for higher cognitive skills, such as creativity.

[70] Forty percent of the increase in demand for cognitive skills in Sweden over the past 20 years was due to the expansion of the ICT sector and a reallocation of engineers among firms. See Christina Håkanson, Erik Lindqvist, and Jonas Vlachos, *Firms and skills: The evolution of worker sorting,* IFN, working paper number 1072, 2015.

[71] Iarla Flynn, *If Europe wants to lead, it needs to invest in digital skills,* Euractiv, November 2, 2017.

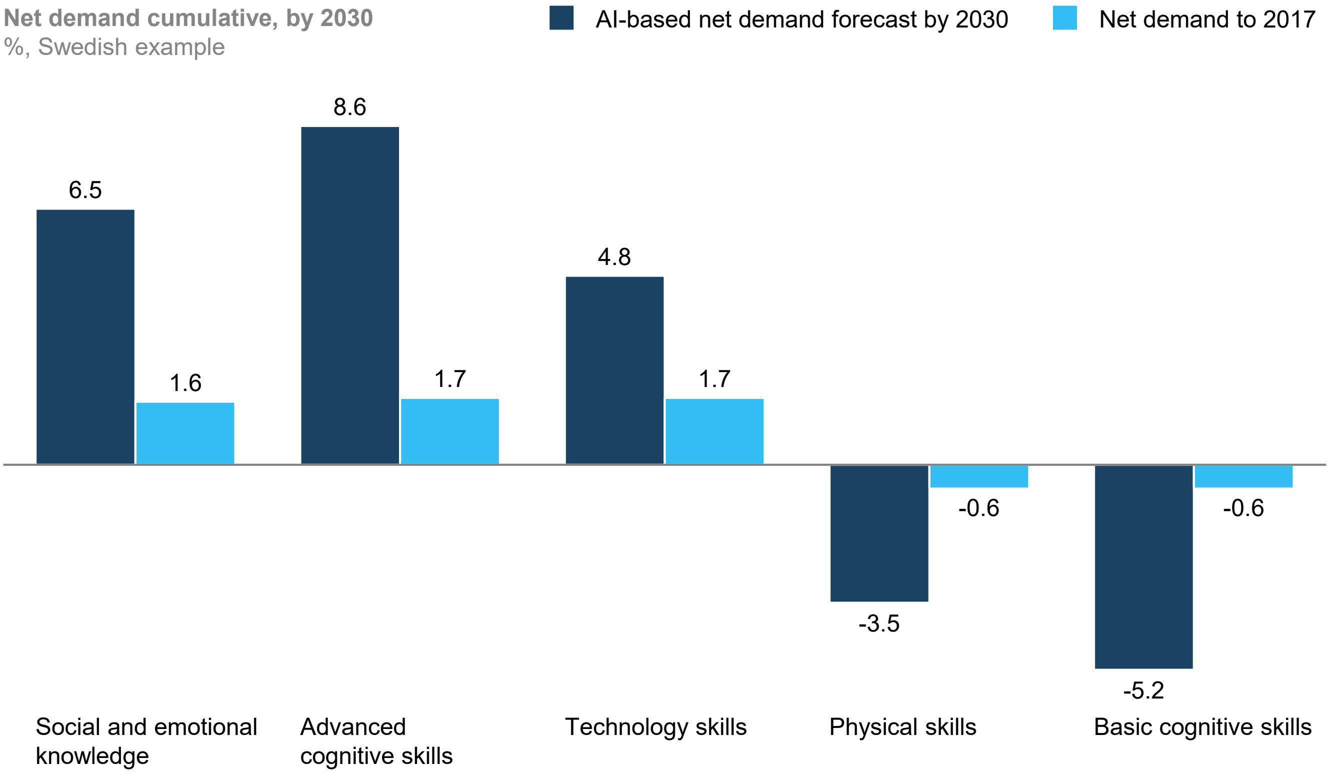
2. Demand for primary physical skills could decline by 3.2 percent a year and demand for basic cognitive skills by 0.5 percent a year. By contrast, demand for social interaction skills could grow by 2.6 percent a year, higher cognitive skills by 1.5 percent, and technology skills by 3 percent.[72]

3. Supply of skills is likely to change, too.[73] However, this shift is likely to happen at a much slower pace than the likely shift in demand, resulting in three types of mismatch: (1) a reduction in primary demand of around 3 percent a year, followed like-for-like by a 2.8 percent-a-year decline in supply of physical skills; (2) a 0.5 percent-a-year reduction in demand for basic skills, but supply still increasing at 0.2 percent as a result of age cohorts and mandatory school systems, leading to a relatively large excess supply; and (3) higher demand, followed by higher supply for higher cognitive and social interaction skills, but supply not increasing as fast as demand in the case of social skills in particular, leading to a long-term mismatch for Sweden.

Overall, this analysis suggests that excess demand may build to about 10 percent of the total workforce by 2030. Such a situation could lead to a significant productivity challenge if not remedied by companies and the education system. Typically, such a level of excess demand implies a war for talent and significant wage pressure on those skills in excess supply in Europe.

Exhibit 15

The change in the skills mix is likely to exacerbate excess demand in advanced cognitive skills and social skills.



NOTE: Labour supply by 2030 is based on pure demographic evolution and no change in the participation rate by age group.

SOURCE: OECD; *Skill shift: Automation and the future of the workforce*, McKinsey Global Institute, May 2018; McKinsey Global Institute analysis

[72] The demand analysis is based on primary skills for each activity and therefore tends to exacerbate changes. In general, the relative change in skill type, whether only primary skills or total skills (both primary and secondary), leads to roughly the same pattern. For more detail, see *Skill shift: Automation and the future of the workforce,* McKinsey Global Institute, May 2018.

[73] Supply of skills can change through new training, and typically new cohorts enter the workforce with skills that are better matched to current needs. Skills training remains low outside large companies, however, and inflows of new skills are only 1 to 2 percent of the stock of workforce skills a year in most European countries.

Implication 3: European countries, industries, and companies that are more AI-innovative are likely to take advantage of winner-takes-most dynamics

Automation and AI are spreading at different paces in various European countries, which could lead to a major bifurcation. On the one hand, there is a winner-take-most, or "superstar", economic effect that has been highlighted in new academic research.[74] On the other hand, a long tail of firms likely are under pressure. To provide a sense of those segments, we can cluster companies by their speed of AI adoption and whether they are only seeking efficiency through AI adoption, or are also striving for more growth from innovation and reinvention. Companies that do not adopt AI are likely to struggle given competitive dynamics, whereas companies that are innovating rapidly may reap disproportionate revenue gains.

That effect is clearly visible today, Our 2018 Digital Survey reports that European companies already investing in any AI technology increase their top-line growth 1.2 points faster—and their earnings before interest and taxes 2.0 points quicker—than do companies that have yet to invest in AI.[75] Furthermore, the (arguably small) sample of European companies that are already fully invested in all AI are increasing their top line 5 points faster than are companies that have yet to adopt any AI technologies, and 3.5 percent faster than companies with only a partial diffusion of AI. If this pace were to continue for about the next ten years, the difference in labour productivity between fully AI-savvy companies and average European companies may be as large as 15 to 20 percent if companies also adjust their employment according to what they said in the survey.[76] This labour-productivity gap in favour of a fringe of so-called superstar firms is in the range of what has been observed in Europe over the past decade. A labour-productivity difference of 20 percent emerged in services (and 12 percent in manufacturing) in France between 2002 and 2012. In Finland, the gap was 15 percent during the same period in both services and manufacturing.[77]

Extrapolating from those dynamics and drawing on our predictions of AI competitive dynamics and the diffusion curve, our modelling exercise suggests that between 35 and 45 percent (the average scenario is 40 percent) of existing European incumbent firms may benefit from a boost to revenue from AI between now and 2030. In contrast, firms that do not adopt, adopt too late, or fail to translate adoption into real innovation could experience a shrinking in their annual revenue. When a new wave of technology hits, pressure on profit is the rule for incumbents except for those that manage to reinvent themselves.[78]

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[74] See *Superstars: The dynamics of firms, sectors, and cities leading the global economy,* McKinsey Global Institute, October 2018. Also see Walter Frick, "The real reason superstar firms are pulling ahead", *Harvard Business Review,* October 5, 2017; and John van Reenen and Christina Patterson, "Research: The rise of superstar firms has been better for investors than for employees", *Harvard Business Review,* May 11, 2017.

[75] One may argue that causality runs both ways—that is, that faster-growing firms invest more in AI; however, we find that growth acceleration from current growth in the next three years is significantly correlated with firms' current level of investment in AI.

[76] Our survey suggests that AI-savvy firms could increase employment by 2 percent, whereas nonadopters may need to shrink employment by 2 percent.

[77] These data are based on preliminary results from the OECD MultiProd project results in April 2016 and were reported by the European Commission. See *Science, research, and innovation performance of the EU,* Directorate-General for Research and Innovation, European Commission, 2016.

[78] This is not to say that half of companies will experience negative profit growth. Our analysis indicates that 25 percent might experience a decline in profits that may not be compensated by the normal baseline growth of the economy. See Jacques Bughin, "The case for digital reinvention", *McKinsey Quarterly,* February 2017. When such firms survive, they can be characterised as "zombie" firms that trap resources and create economic inefficiencies. That phenomenon has already been visible since the most recent recession that was compounded by slow digital diffusion in Europe, especially in laggard countries. In Spain, for instance, the share of zombie firms increased from 3 percent of all companies (accounting for 5 percent of employment) in 2007 to 10 percent of firms (and 12 percent of employment) by 2013. See *10 trends shaping innovation in the digital age,* European Commission, May 16, 2018.

We are likely to witness a fringe of powerful European incumbent companies that are not only fully invested in AI but also use AI technologies largely to innovate. Those companies would display winner-takes-most features, on average increasing revenue by double digits a year as a result of AI diffusion, all other things being equal. The size of those winners and their revenue growth going forward would likely be highly sector specific because that growth depends on industry dynamics of diffusion and the benefits of innovation versus pure efficiency gains. At one extreme, in construction, we estimate that between 2 and 5 percent of European companies could grow their revenue at a powerful growth rate of about 10 percent—that is, three times the forecast sector growth in Europe.[79] A majority (in our modelling, between 55 and 65 percent of construction companies), however, may find that their revenue may be put under pressure through AI. At the other extreme, in the ICT sector, a larger fringe (in our modelling, possibly more than 10 percent of companies) may increase revenue by more than 15 percent a year, but only a minority (in our modelling, less than 25 percent of companies) may experience pressure on revenue (Exhibit 16).[80]

Although innovative AI first-mover firms could be a fringe of incumbent European companies, nurturing them is still vital not only to secure economic growth in the Eurozone (so that what they generate in extra revenue is as large as the revenue loss of the nonadopting firms) but also because they are expanding, rather than reducing, their workforces.

3. AI COULD GIVE EU ECONOMIES A STRONG BOOST

If Europe were to scale up AI according to the three factors noted—and according to its current set of skills, state of digitisation, and other skills and assets to date—it could potentially add up to €2.7 trillion in GDP to its combined economy of €13.5 trillion, resulting in 1.4 percent in compound annual growth through 2030 (or 19 percent cumulative). Europe may also be close to maintaining the same level of full-time employment as today—but employment with a higher skills profile.

That potential is not likely to be achieved automatically, but rather results from an effective combination of diffusion, innovation, and skills upgrades that rests on the assumption that Europe's relative position in assets and competencies for AI does not erode over time. If Europe improves on its assets and competences sufficiently to catch up with the United States' AI frontier, the potential could be even higher. GDP growth could accelerate by another 0.5 point a year, adding an extra €900 billion to GDP and bringing the total potential AI boost to €3.6 trillion by 2030 (see Box 3, "Modelling approach and limitations").[81]

AI COULD DELIVER AN ADDITIONAL €2.7 BILLION OF ECONOMIC ACTIVITY IN EUROPE

Our estimate of the potential economic impact in Europe takes the same micro-to-macro simulation approach as in our global research on the economic impact of AI.[82] The model covers the period from 2017 to 2030 as a delta from an economic baseline for the EU-28 countries and relies on bottom-up diffusion of AI by firms, including the transition cost of AI deployment and competition among firms, both domestically and through cross-border flows of investment, trade, and data (Exhibit 17).

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79 The forecast for the Western European construction sector is between 2.7 and 3.1 percent a year from now to 2020. See *European construction market forecast from 2015 to 2020: Overview of the European construction market,* Building Radar, July 10, 2015 (https://buildingradar.com/construction-blog/european-construction-market-forecast/).

80 Those figures are based on everything being equal—regarding revenue distribution out of AI—but do not include other drivers of demand.

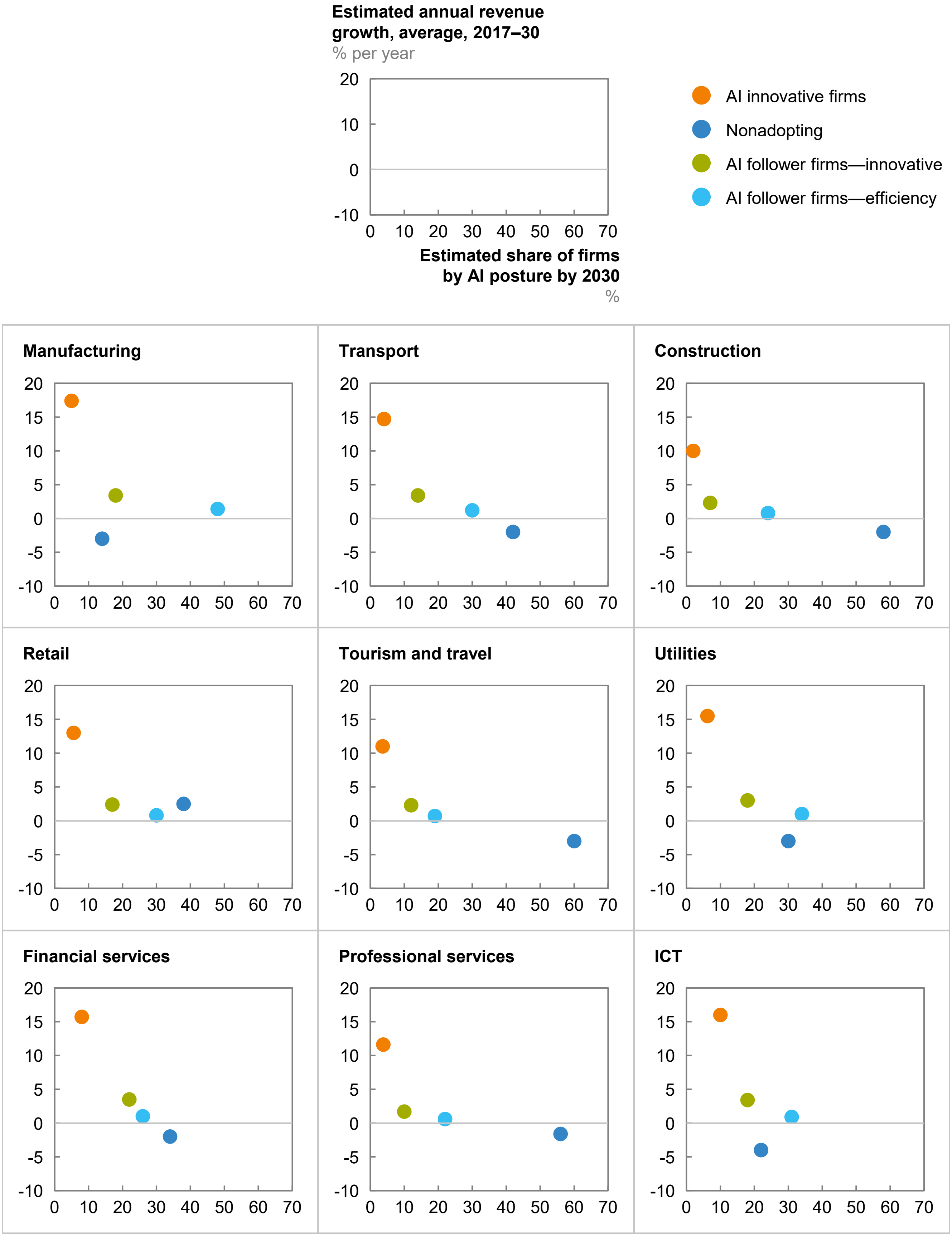
81 Globally, AI could potentially deliver additional economic output of around $13 trillion by 2030, boosting global GDP by about 1.2 percent a year. See *Notes from the AI frontier: Modeling the impact of AI on the world economy,* McKinsey Global Institute, September 2018.

82 McKinsey, *Notes from the AI frontier.*

Exhibit 16

Revenue growth is expected to depend on AI posture.

EU-28

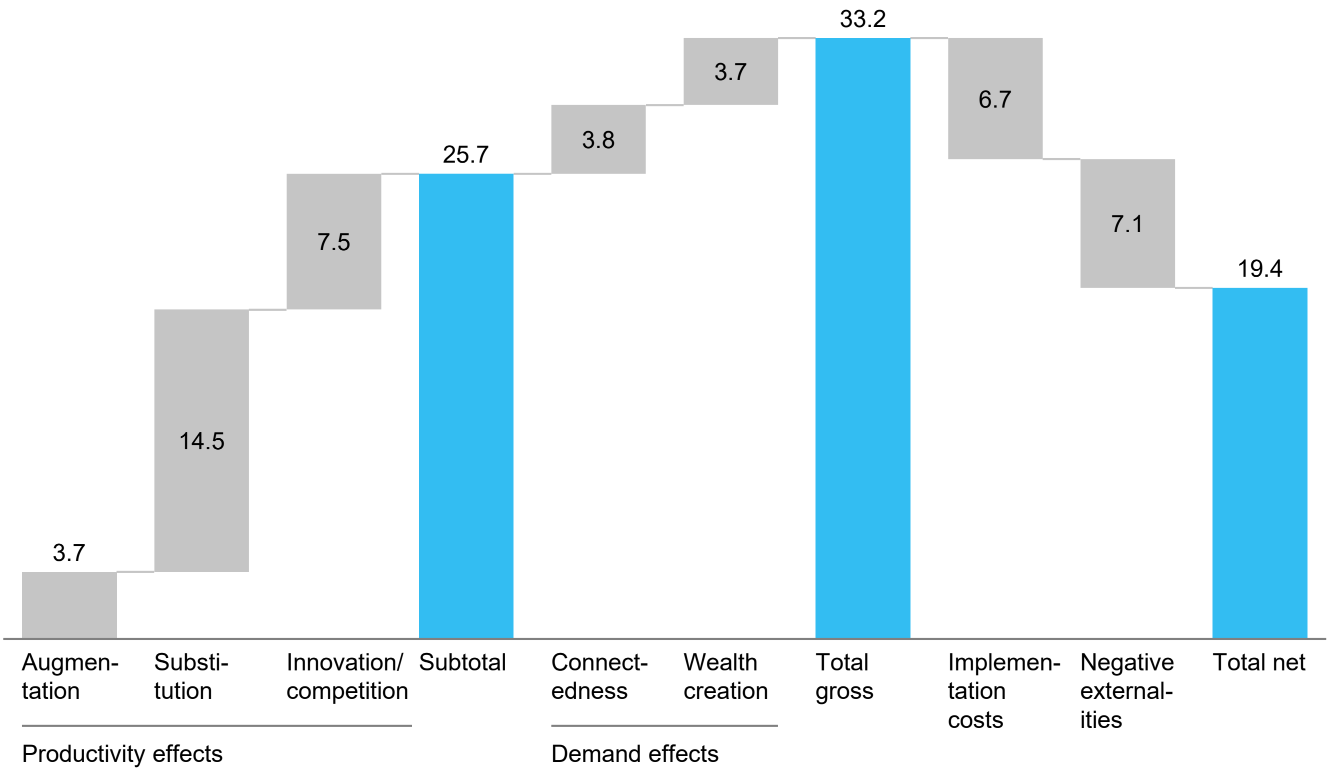


SOURCE: VivaTech survey, 2017; McKinsey Global Institute AI Diffusion Model; McKinsey Global Institute analysis

Exhibit 17

On average, AI could boost growth in European economic activity by close to 20 percent by 2030.

GDP growth, EU-28 countries, 2030, average scenario
%



SOURCE: McKinsey Global Institute AI Diffusion Model; McKinsey Global Institute analysis

We calibrate the total effect on both growth and employment of seven core macroeconomic and microeconomic enablers, focusing on three macroeconomic enablers:

- **Automation potential.** Depending on the wage level, economics and social acceptance, the automation potential, and therefore substitution effect, may differ. For instance, countries with lower relative wages such as Romania may have less labour automation potential than Scandinavian countries.

- **Investment capacity.** Investment can facilitate the development of new technologies, incubate new businesses, and drive the creation of new jobs associated with AI directly and indirectly. For example, investment-to-GDP ratios are relatively low in Southern European economies, in part due to the recent European crisis.

- **Connectedness.** Countries can benefit from stronger connectedness to the world especially if they can be suppliers to the AI value chain and innovate and export more products and services to the global market. For instance, the Netherlands is one of the most data-connected countries in the world, according to DHL research.[83]

[83] *DHL Global Connectedness Index: Globalization surpassed pre-crisis peak, advanced modestly in 2015,* tralac, December 12, 2016, https://www.tralac.org/news/article/10984-dhl-global-connectedness-index-globalization-surpassed-pre-crisis-peak-advanced-modestly-in-2015.html.

Box 3. Modelling approach and limitations

This research focuses on AI's potential impact on global economic activity at the country, sector, company, and worker levels, using simulation.

- **Scope.** We only focus on the economic effects of productivity and employment. We do not consider other important aspects, including ethics and cybersecurity, or the effect of these technologies on sustainability or inclusive growth, nor do we quantify aspects of the consumer surplus that may arise from using AI technologies, such as saving time or living a healthier life.[1]

- **Definition of AI used in the economic modelling.** Characterising AI precisely is difficult because the definition tends to change depending on the specific context of research and application.[2] For the purposes of our modelling, we employed a narrower view of AI that focuses on deep learning techniques (especially feed-forward neural networks, recurrent neural networks, and convolutional neural networks).[3] The company-level survey used for our modelling of AI adoption and absorption covers five broad set of AI technologies, namely computer vision, natural language, virtual assistants, robotic process automation, and advanced machine learning.

- **Data sources.** We used both AI-specific and macroeconomic data sets. For AI-specific data, we used three sources, as described in Box 1. For macroeconomic data, we used statistics from external organisations, including the United Nations, the World Bank, the Organisation for Economic Co-operation and Development (OECD), the World Economic Forum, and mostly Eurostat/Cedefop.

- **Approach to AI adoption and full absorption.** The concepts of adoption and full (and partial) absorption have been used in various contexts. In this research, we use an economic entity—a company—and its activities as a unit for adoption. Adoption of AI is when that entity chooses to invest in one of the five generic AI technologies either for experimentation or for a narrow functional use.[4] Full absorption means that all five generic AI technologies are adopted and integrated into broad enterprise workflows. Full absorption is the stage at which economic benefits tend to kick in and recur.[5] However, we note that full absorption does not imply a fixed range of technologies. New technologies and applications

1 *Testing the resilience of Europe's inclusive growth model,* McKinsey Global Institute, December 2018.
2 See *A future that works: Automation, employment, and productivity,* McKinsey Global Institute, January 2017; and *Jobs lost, jobs gained: Workforce transitions in a time of automation,* McKinsey Global Institute, December 2017.
3 *Notes from the AI frontier: Insights from hundreds of use cases,* McKinsey Global Institute, April 2018.
4 This information is based on our surveys. Generic AI technologies include machine learning, robotics, and other AI application tools, such as virtual assistants, computer vision, and voice recognition.
5 Jacques Bughin, "The diffusion pattern of Enterprise 2.0 technologies: Worldwide estimates of a bass co-diffusion model for the last 10 years", *Journal of Contemporary Management,* December 2016; and Jacques Bughin and Michael Chui, "The rise of the networked enterprise: Web 2.0 finds its payday", *McKinsey Quarterly,* December 2010.

We focus on four microeconomic enablers:

- **Digital legacy.** As digitisation precedes AI adoption and diffusion, digital maturity can be a good indication for assessing the potential of different economies. Previous MGI research pegged the United Kingdom as the most digitised European economy to date.[84] Countries such as Estonia—after its separation from the Russian bloc—have also leapfrogged on their digitisation.

- **Innovation foundation.** The degree of innovation can determine whether a country is able to develop and commercialise powerful AI solutions. Innovative capacity is relatively large in countries such as Sweden, for instance, as noted by the World Economic Forum.[85] The country also has a vibrant set of deep tech and AI startups.[86]

84 *Digital Europe: Pushing the frontier, capturing the benefits,* McKinsey Global Institute, June 2016.
85 John McKenna, *South Korea and Sweden are the most innovative countries in the world,* World Economic Forum, February 6, 2018.
86 Jacques Bughin, Laura LaBerge, and Anette Mellbye, "The case for digital reinvention", *McKinsey Quarterly,* February 2017.

will continue to emerge. In this report, we use the term "full" as opposed to "partial" to indicate much broader use of AI technologies than is the case in adoption or in a pilot.

- **Limitations and sensitivities.** Our firm-level simulation is dependent on the quality of data from the surveys used as inputs, and we acknowledge that this approach has two potential limitations. First, survey answers depend on the knowledge and perceptions of respondents, and their understanding of AI may vary, possibly affecting the quality of the insights and data gathered in this way. Second, the data set from our survey results may be skewed toward early movers. Extrapolating insights from the survey may therefore lead us to overestimate the economic impact because the next wave of companies adopting AI may display different behaviour in terms of AI adoption. As new data continue to be gathered, the adoption and full absorption curve and the results of the simulation could change.

- **Simulation and econometrics approach.** MGI's econometrics team and a team from the Free University of Brussels independently analysed both surveys previously mentioned.[6] Both teams estimated and converged on the dynamics of propensity to adopt and absorb technologies. Each team found that consistent dynamics of adoption and absorption were visible in both samples used. Our simulation of economic impact and competitive dynamics also drew on academic literature (for further detail on our econometric approach, see the technical appendix).[7] We calibrate the estimated impact on the basis of the seven relevant enablers we have noted.

We note that although we report simulated figures emerging from this analysis, the numbers presented in this paper *should not* be read as forecasts but rather are intended to provide a directional perspective on the potential economic impact of AI.

6 The results of these surveys have been discussed previously in Jacques Bughin, "Wait-and-see could be a costly AI strategy", *MIT Sloan Management Review,* June 15, 2018; and Jacques Bughin, Tanguy Catlin, Martin Hirt, and Paul Wilmott, "Why digital strategies fail", *McKinsey Quarterly,* January 2018.

7 Aghion and Jones studied AI's effect on production function. See Philippe Aghion, Benjamin F. Jones, and Charles I. Jones, *Artificial intelligence and economic growth,* October 10, 2017. Korineck and Stiglitz explored the surplus accruing to innovators, analysis on which we drew in our simulation of economic impact for front-runners and nonabsorbers. See Anton Korinek and Joseph E. Stiglitz, *Artificial intelligence and its implications for income distribution and unemployment,* NBER working paper number 24174, December 2017. Acemoglu and Restrepo undertook various simulations on capital and labour relationships and the impact of automation on employment and wages. See Daron Acemoglu and Pascual Restrepo, *Artificial intelligence, automation, and work,* NBER working paper number 24196, January 2018; and Daron Acemoglu and Pascual Restrepo, *Modeling automation,* National Bureau of Economic Research (NBER) working paper number 24321, February 2018.

- **Human capital.** Human capital is critical to the absorption of new knowledge and its real-world application. Finland, for example, is known for the excellence of its education system and vocational training.[87]

- **AI ecosystem maturity.** A powerful digital ecosystem that leads to enough AI startups to exploit and deliver platforms and applications is an important driver of a vibrant local ICT sector, with large possible spillovers in each economy. To date, the United Kingdom and countries in Northern Europe are ahead of other European countries in their origination of AI startups.[88]

In general, Europe fares well with regard to its automation potential and in the stock of cognitive skills. As we have highlighted, however, Europe has not been able to increase its innovative capacity, with corporate R&D stagnating, and is challenged in the buildup to date of large AI startup ecosystems and in its external digital ICT balance of products, services, and foreign direct investment (FDI) (Exhibit 18).

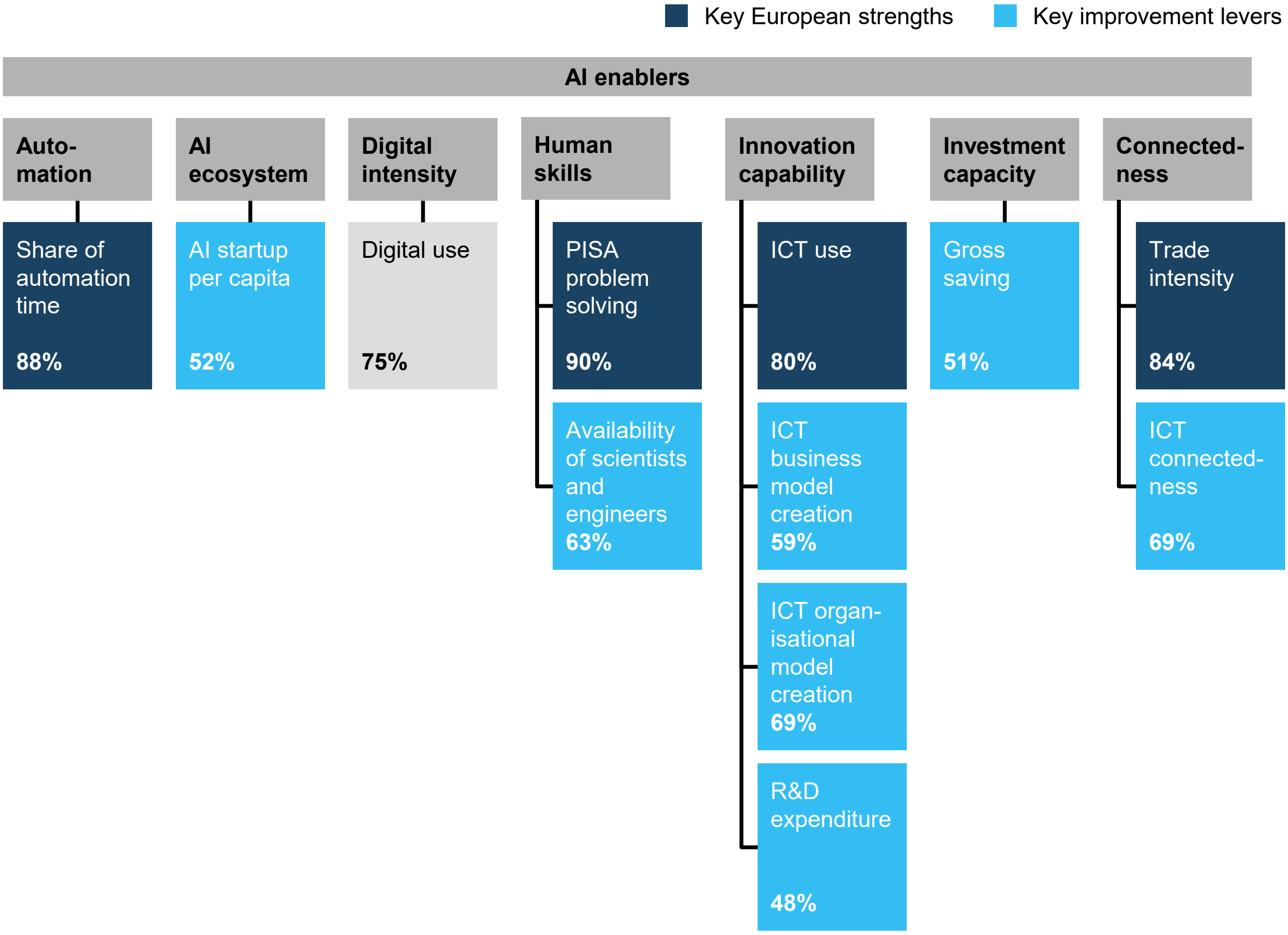
87 *Literacy in Finland,* Country report, European Literacy Policy Network, March 2016.

88 In our original work, we considered also how social protection is an important enabler of the AI transition. Countries with more extensive social protection and systems favouring retraining may minimise the transitional cost of AI diffusion. As highlighted in other MGI research, Scandinavia's type of social contract is characterised by large social benefits and more intensive cooperation between firms and workers. See *Testing the resilience of Europe's inclusive growth model,* McKinsey Global Institute, December 2018.

Exhibit 18

The average European country is below the frontier for maximising the potential of AI.

Index; 100% = maximum observed in sample of 45 counties worldwide



SOURCE: Eurostat; INSEAD; Directorate-General for Research and Innovation, European Commission; Programme for International Student Assessment (PISA); UNESCO; McKinsey Global Institute Diffusion, Productivity, and Automation Model; McKinsey Global Institute analysis

Despite its current state, at 60 percent of the frontier, we nevertheless estimate that, on average, the European economy could still expand by about 19 percent by 2030. Given nominal GDP of Europe of €14 trillion in 2017, that is equivalent to a total value added increase of €2.7 trillion, or compound annual growth in economic activity of 1.4 percent a year, in the period to 2030. That is a material potential economic impact at around double the typically calculated effects of other general-purpose technologies adopted by developed countries in the past.[89] It is also in the range of the full potential available from rolling out a fully formed and implemented digital single market.[90]

[89] As benchmarks, the economic impact on labour productivity from the introduction of steam engines during the 1800s was only an estimated 0.3 percent; the impact from robots during the 1990s, around 0.4 percent; and the spread of IT during the 2000s, between 0.6 and 0.9 percent. See *A future that works: Automation, employment, and productivity,* McKinsey Global Institute, January 2017. Also see Nicholas Crafts, "Productivity growth in the Industrial Revolution: A new growth accounting perspective", *Journal of Economic History,* Volume 63, Issue 2, June 2004; Nicholas Crafts, "Steam as a general purpose technology: A growth accounting perspective", *Economic Journal,* Volume 114, Issue 495, April 2004; Mary O' Mahony and Marcel P. Timmer, "Output, input, and productivity measures at the industry level: The EU KLEMS database", *Economic Journal,* Volume 119, Issue 538, June 2009; and George Graetz and Guy Michaels, *Robots at work,* Centre for Economic Performance discussion paper number 1335, March 2015.

[90] See *Digital single market: Bringing down barriers to unlock online opportunities,* European Commission (https://ec.europa.eu/growth/single-market/digital). The European Commission estimates that a fully functional digital single market would promote innovation, contribute €415 billion to the EU economy each year, and create hundreds of thousands of new jobs.

We considered a wide range of channels that produce the effect. Three-quarters of the gross economic impact is likely to come from enhanced productivity; AI-induced demand accounts for the rest. On the supply side, automation has the largest (but not exclusive) effect, followed by complementary inputs and more and better innovation. Automation largely affects labour, but it also affects capital through, for instance, preventive maintenance. Innovation through AI also is a material driver of GDP growth, bringing about 0.5 percent of growth per year.

Two demand-side factors may play out and increase the total economic growth effect. The first is a wealth creation effect, as gains in productivity can create new consumption spillover effects that boost economic growth. Those secondary effects develop over time and have been relatively large in the services share of the European economy.[91] They have been a major source of sustained growth in Europe, adding 0.3 to 0.5 points to annual growth to Europe in recent decades.[92] We estimate that the wealth effect from AI is of relatively the same magnitude as in the past.

The second demand-side channel exists because most European economies are not insular; they are part of the global marketplace. In 2014, trade in goods and services made up close to a third of the EU-28's GDP.[93] MGI research has emphasised that a large part of international cross-border flows is now in the form of digital data, with the Netherlands and Germany being more central to those flows than are other European countries.[94] Those data flows have already given European economies a material boost, at 30 basis points a year of growth in the long run.[95] AI may add to the positive effect of data flows, roughly to the same degree as digital flows in the recent past.

To build an AI-led growth path, an estimated 40 percent of the potential would likely need to be spent during the transition. Slightly less than half of those costs would likely be linked to transition and implementation costs, mostly to be borne by firms adopting and absorbing AI and redeploying and reskilling their workforces. The other half of the costs relates to negative externalities that may arise from the new work with machines, including temporary unemployment.

EUROPE MAY ACHIEVE A PRODUCTIVITY BOOST THROUGH AI WITHOUT SACRIFICING EMPLOYMENT

Throughout history, technology has eliminated some types of jobs, but it also always created new ones.[96] The creation of jobs often occurs as new roles are needed to complement the effective operations of new technologies, or as large productivity gains form technology diffusion-created extra gains that are reinvested back into the economy.

Over the past 15 years in Europe, technology has created more jobs than it has destroyed, resulting in a net positive of three million to 11 million jobs in Europe after a decade, according to recent academic estimates, which has neutralised the impact of the "crisis" on employment.[97] In recent years, while US employment stagnated, employment slightly increased in Europe. However employment evolves, we know that Europe, Japan, and the United States have all experienced a similar shift in the mix of skills in demand in their economies, with demand for medium-skill routine jobs falling but demand for high cognitive and social skills rising.[98]

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[91] See *Information technology and the U.S. workforce: Where are we and where do we go from here?* The National Academies of Sciences, Engineering, and Medicine, 2017; and David Autor and Anna Salomons, *Does productivity growth threaten employment? "Robocalypse now?",* European Central Bank Annual Conference, Sintra, Portugal, June 27, 2017.

[92] Terry Gregory, Anna Salomons, and Ulrich Zierahn, *Racing with or against the machine? Evidence from Europe,* ZEW discussion paper number 16-053, 2016.

[93] Eurostat data.

[94] *Digital globalization: The new era of global flows,* McKinsey Global Institute, March 2016.

[95] Jacques Bughin, "Cross-border data flows and growth in Europe", *DigiWorld Economic Journal,* third quarter, Issue 107, 2017.

[96] *Jobs lost, jobs gained: Workforce transitions in a time of automation,* McKinsey Global Institute, December 2017.

[97] Gregory, Salomons, and Zierahn, *Racing with or against the machine?.*

[98] *Skill shift: Automation and the future of the workforce,* McKinsey Global Institute, May 2018.

It is, of course, impossible to predict with any precision all of the jobs that are likely to be created through AI, just as it would have been impossible to imagine employment for web developers and social media marketers 50 years ago. Offering a rough estimate, however, we contend that in the EU-28, on average, AI could enable the creation of as many new jobs as jobs that are changed, although—again, on average—the logic of smart automation may imply that the total number of job hours created may fall just short of job losses by 2030. MGI's previous work on AI and automation came to the same conclusions and even suggests that, under certain conditions, employment may be maintained, even with the diffusion of AI.[99] One reason is that, in general, economic growth is not exclusive to technology (even if the latter is an important contributor) and may continue to require some employment.

Other critical factors may affect total employment in the long term. The first relates to the level of ICT and digital skills. Based on early work benchmarks, seven million new jobs that did not exist before could be added to the European economy as the result of new products and services enabled by AI.[100] Those new types of jobs are likely to be concentrated in ICT and digital skills and would include, among others, cybersecurity experts, big data analysts, and coders. One-third of new jobs created in the United States in the past 25 years did not exist 25 years ago, and 70 percent of them were linked to technology.

A potential employment split could be 25 percent creating and supplying technology (or roughly 1.8 million FTEs), 40 percent enabling adoption (or roughly three million), 25 percent utilising and building on technology, and some 10 percent (or about 0.8 million) in other related occupations.[101]

- **Creators and suppliers of technology.** These occupations are directly involved in the creation of automation technology and infrastructure (for example, engineers for the Internet of Things, robot designers, and software developers). Europe's issue is that it may not be fully capturing the potential to date for this category of jobs. In general, Europe has a smaller ICT sector than do other frontier countries, such as the United States, and, furthermore, has been a net importer of digital services to date.

- **Enablers.** These are participants in ecosystems that help maximise the value added by technology. Key examples are data analysts and creators of business insights. One of Europe's challenges is its ability to supply those types of jobs. Currently, ICT graduates account for fewer than one per one thousand of the working population, and their number is growing at a rate of only 5 percent a year, which is not sufficient to meet the full need we anticipate. The European Commission estimates up to 500,000 vacancies for ICT professionals in Europe in the next five years.[102]

- **Utilisers and other related jobs.** These jobs will typically arise in knowledge-intensive industries. The first category refers to jobs linked to new applications for automation technologies, such as those relating to big data and advanced analytics. The second category concerns occupations that might include, for instance, legal experts and accountants. Europe's issue here is that the concentration of employment in knowledge-intensive industries has remained constant over the past five years, at about 13 percent of total employment. In contrast, in the United States, jobs in knowledge-intensive business activities already account for 17 percent of the total.[103]

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99 *Jobs lost, jobs gained: Workforce transitions in a time of automation,* McKinsey Global Institute, December 2017.

100 Jeffrey Lin, "Technological adaptation, cities, and new work", *Review of Economics and Statistics,* Volume 93, Number 2, May 2011.

101 *Digitally enabled automation and artificial intelligence: Shaping the future of work in Europe's digital front-runners,* McKinsey & Company, October 2017.

102 *Science, research, and innovation performance of the EU,* Directorate-General for Research and Innovation, European Commission, 2016.

103 *Science, research, and innovation performance of the EU.*

The second driver of employment is innovation. Europe's issue here is that performance is mixed. Looking at business dynamism, Europe's share of high-growth enterprises—at 4 percent of total companies—is rather higher than that of the United States. Europe also has relatively healthy entrepreneurism in its population, with 12 percent of its working-age population already latent entrepreneurs who, according to Global Entrepreneurship Monitor, intend to start a business in the next three years.[104] Entrepreneurial dynamism is concentrated only in very small enterprises, however, and it is unclear how long it will take for this dynamism to translate into a significant macroeconomic impact on employment in Europe. Innovation in large enterprises in Europe lags behind that of its US counterparts. In fact, the R&D intensity of US firms is higher and increasing, whereas that of European firms is stagnating.[105]

In total, the effect of AI on employment is highly sensitive to how Europe's product and labour markets interact with technology diffusion. An increase in innovative ability may lead to half proportional increase in employment by 2030. Obviously, the opposite is also true. If Europe loses out on innovation in the AI race, it risks more job changes than possible jobs gained. In addition, the employment figures assume the same working time per job as today; however, in past decades, average weekly hours worked have systematically declined, according to the EU Labour Force survey.[106] The same change would be sufficient to stabilise the overall number of jobs. Finally, the transition to new jobs must develop quickly; if it doesn't, frictions may build and create major mismatches, as we have noted.

The message is therefore clear—more AI innovation, fluidity in job reallocation, and internalisation of AI gains within Europe is likely to determine the fate of job development in the region. Powerful development of AI may be the best hedge and may even be the catalyst for new jobs in Europe in the future.

AI MAY BRING MORE OPPORTUNITIES IF EUROPE CONVERGES WITH THE WORLD'S AI LEADERS

At the current relative performance of enablers, versus other continents, Europe would still lag behind world AI leaders such as the United States in terms of the potential on offer. In fact, we estimate that the United States is 31 percent ahead of Europe in the AI-enablers frontier.

Europe trails the United States for at least two reasons. The first is that the EU-28 lags behind the United States on digital technologies, with a deficit in digital-enabled and ICT services in the range of $50 billion.[107] The United States has been able to generate 1.5 to 2 times more patents per capita than has Europe in digital, quantum computing, and big data. Moreover, the ratio of AI-related patents granted in the United States vs. Europe has grown from less than 2.0 in 2005 to more than 2.5 in 2015, evidence that the gap is widening—and, in fact, doubling in the case of Europe versus the United States (Exhibit 19).[108] Europe's gap with the United States is visible not only in trade but also in foreign direct investment (FDI), in which the difference between US affiliates in Europe and vice versa is double that linked with trade. The gap may also widen with the diffusion of AI and therefore compensate for the trade gap; however, AI could also lead to a wider gap in incomes between Europe and the United States, as a portion of economic profits from FDI may well flow back to the home country, with a negative effect on the destination country because those profits are not reinvested in the local economy.

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[104] *Global report 2016/17,* Global Entrepreneurship Monitor, 2017.

[105] *Science, research, and innovation performance of the EU.*

[106] *Comparative analysis of working time in the European Union,* European Foundation, November 15, 2009.

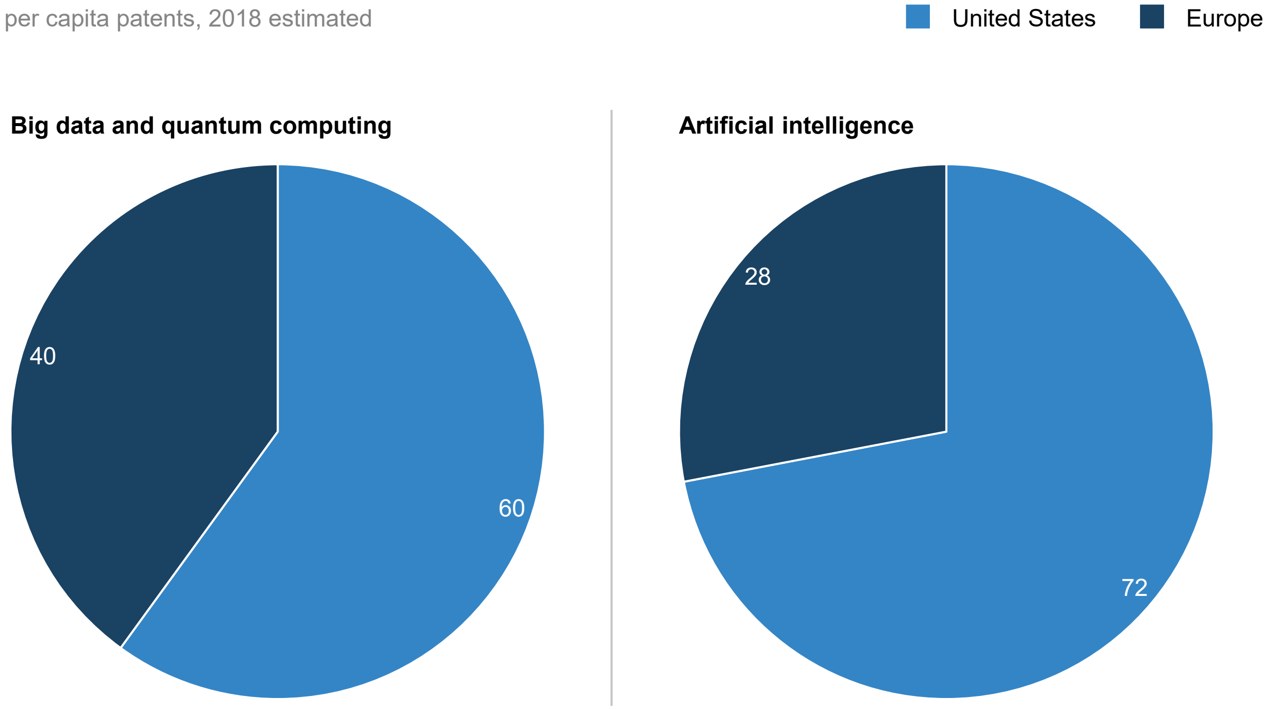
[107] The U.S. Department of Commerce estimates a $75 billion trade surplus for the United States versus Europe, about one-third of which is pure ICT and digital and the other two-thirds potentially digitised services. Roughly 50 percent is fully digitised, leaving about $50 billion in digitally enabled commerce. See Jessica Nicholson, *ICT-enabled services trade in the European Union,* U.S. Department of Commerce, ESA Issues Brief Number 3, 2016.

[108] These ratios are based on data on patents filed in the top five offices worldwide, collected by OECD Science Technology and Industry scorecards and United Nations demographic data.

Exhibit 19

Europe has a deficit with the United States on advanced technology patents.

% of per capita patents, 2018 estimated



NOTE: Figures may not sum to 100% because of rounding.

SOURCE: Directorate-General for Research and Innovation, European Commission; European patent offices; SRI; McKinsey Global Institute analysis

The second reason Europe may end up lagging further behind the United States is a diffusion effect. As we have already discussed, Europe is already 20 percent slower than the United States in terms of corporate adoption of AI. The gap is not likely to close automatically because diffusion dynamics are network based, and the dynamics tend to create agglomeration effects in skills, capital, and education, as we observed in Silicon Valley in the United States.[109] Further, as is well known, Europe's gap with the United States on innovation capital has widened over the past decade, reflecting, in particular, an increase in R&D intensity in US firms but flat intensity in their European counterparts.

Overall, therefore, Europe's current relative position is in danger of deteriorating. A plausible deterioration of 10 percent on two key enablers—innovative ability and skills—could lead to a loss of 16 percent of the potential, or roughly €400 billion. Likewise, and everything else being equal, we find that Europe attaining the current frontier with the United States could potentially create an additional boost to GDP of €900 billion by 2030 and could close Europe's employment gap. The latter effect arises because of improved innovation in general and because of higher capture of profit pools linked to AI ecosystems.

[109] This skill agglomeration has been demonstrated in academic studies on big data analytics. See, for instance, Prasanna Tambe, *Big data investment, skills, and firm value,* MIT IDE Research Brief, Volume 2016.09, 2014. As we discuss later in this paper, we estimated a production function of AI startups at the country level and found that AI funding and AI skills are typically combined to produce a disproportionate number of startups.

4. AI PERFORMANCE IS LIKELY TO VARY AMONG EU MEMBER STATES

As we have noted, the total effect of AI on GDP and employment growth depends on whether a set of core enablers are in place—and are nurtured. Those enablers are present to differing degrees in EU member states, and therefore we might expect very different performance on AI if those differences persist.

We collected a set of indicators by country to gauge how they stand on the key enablers. For readability, we aggregated those indicators into an AI Readiness Index. Index scores are not pure averages but are based on weighting each enabler according to its relative importance for boosting the economic growth of each country. For instance, the presence of a vibrant AI ecosystem, an ability to innovate, and sufficient human skills to power the necessary shift in skills needed in the AI era have double the effect on AI-led growth than, say, connectedness, the reinvestment rate, or digital readiness (the latter becoming obsolete over time).

We computed and normalised the index not only for European countries but also for more than 45 countries for which we were able to collect comparative data (Exhibit 20).

The following are some of the findings:

1. The most advanced Northern European countries and the Anglo-Saxon countries lead in Europe, ahead of China but behind the United States.

2. The United States leads the index, driven by a strong AI ecosystem, positive ICT connectedness, and strong innovation capabilities. China is notably able to reinvest lots of AI-related gains into its economy, and is already deploying AI ecosystems. In general, automation potential is lower in China than in Europe because of lower incentive to arbitrage salaries.

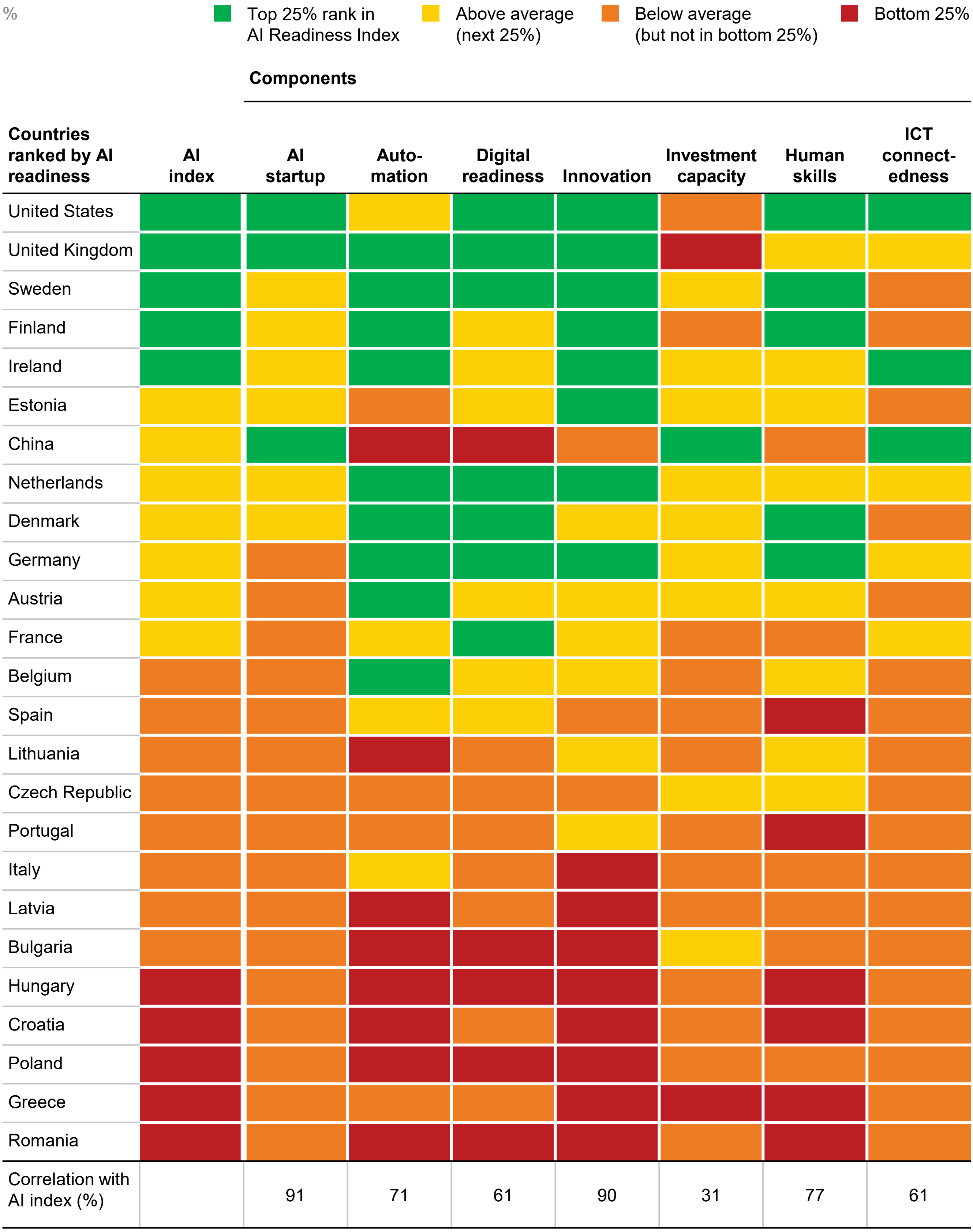
3. A clear gap in AI readiness exists, with Southern and Eastern Europe lagging. The main driver of differences between the most AI-ready and the least reflects slower AI adoption in less ready countries that limits the potential benefits of the competitive race to AI, lower skills with which to reap the benefits from AI, and a lower share of innovative firms leveraging AI.

4. European countries have very different strengths and weaknesses on the enablers. For instance, Ireland tops the index on ICT connectedness, Finland on human capital, and the United Kingdom on innovation. The dispersion of strengths indicates that countries can borrow best practice from each other to create a more favourable and more enabling environment for AI.

In general, we should also expect that the AI index, which measures how close countries are to being able to fully exploit AI, should be a strong predictor of the ability to generate employment and output growth through AI. Indeed, we find that pushing AI can potentially and simultaneously create more growth and more jobs in more AI-ready countries (Exhibit 21).

Exhibit 20

There is a large spread of AI readiness in Europe, but even the most ready countries are behind the US AI frontier.



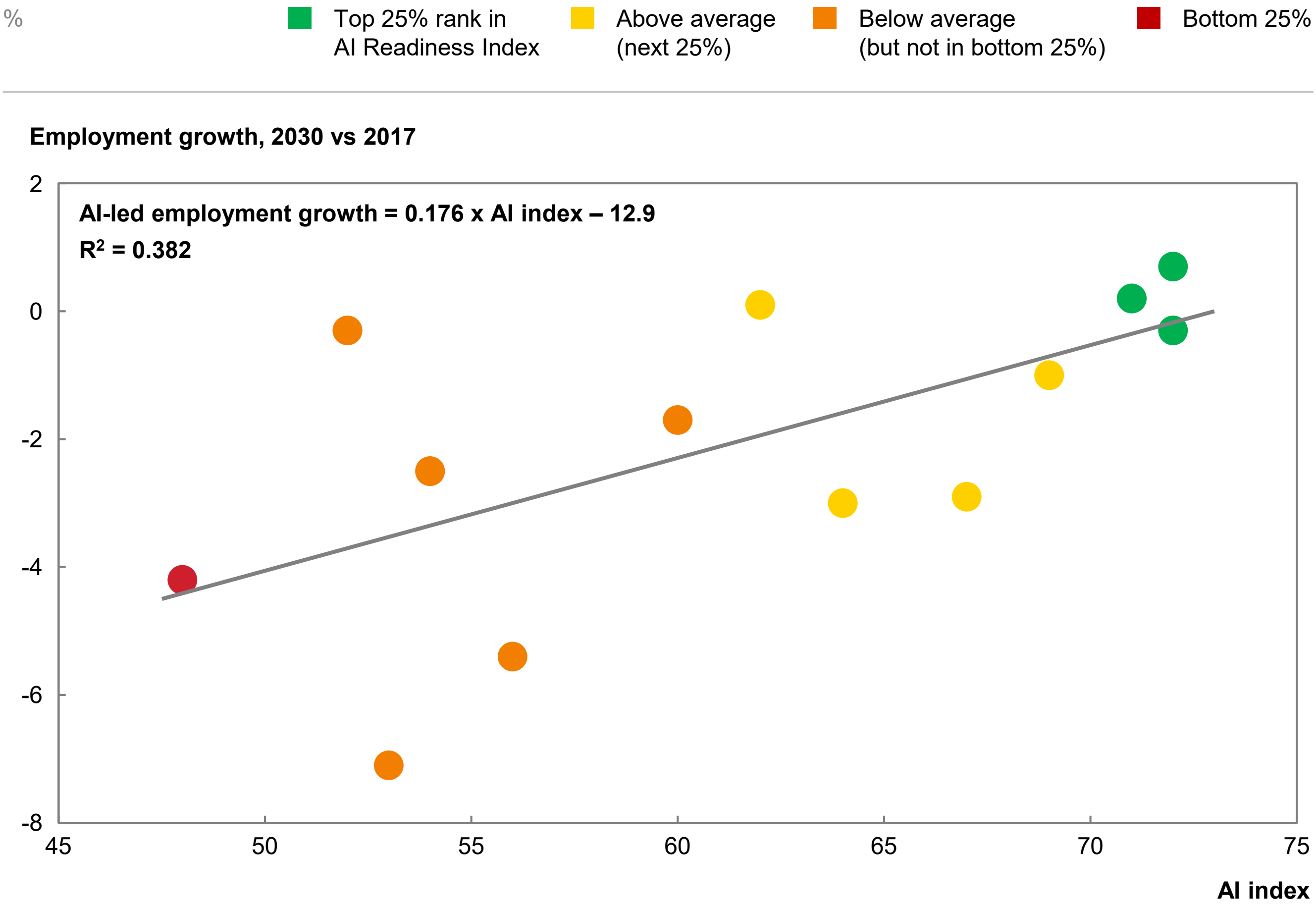
NOTE: The AI Readiness Index measures where countries stand across a range of AI enablers, including the number of AI startups per capita, automation potential of job activities, digital maturity, the availability of scientists and engineers, ICT business model creation, R&D expenditure, and ICT connectedness.

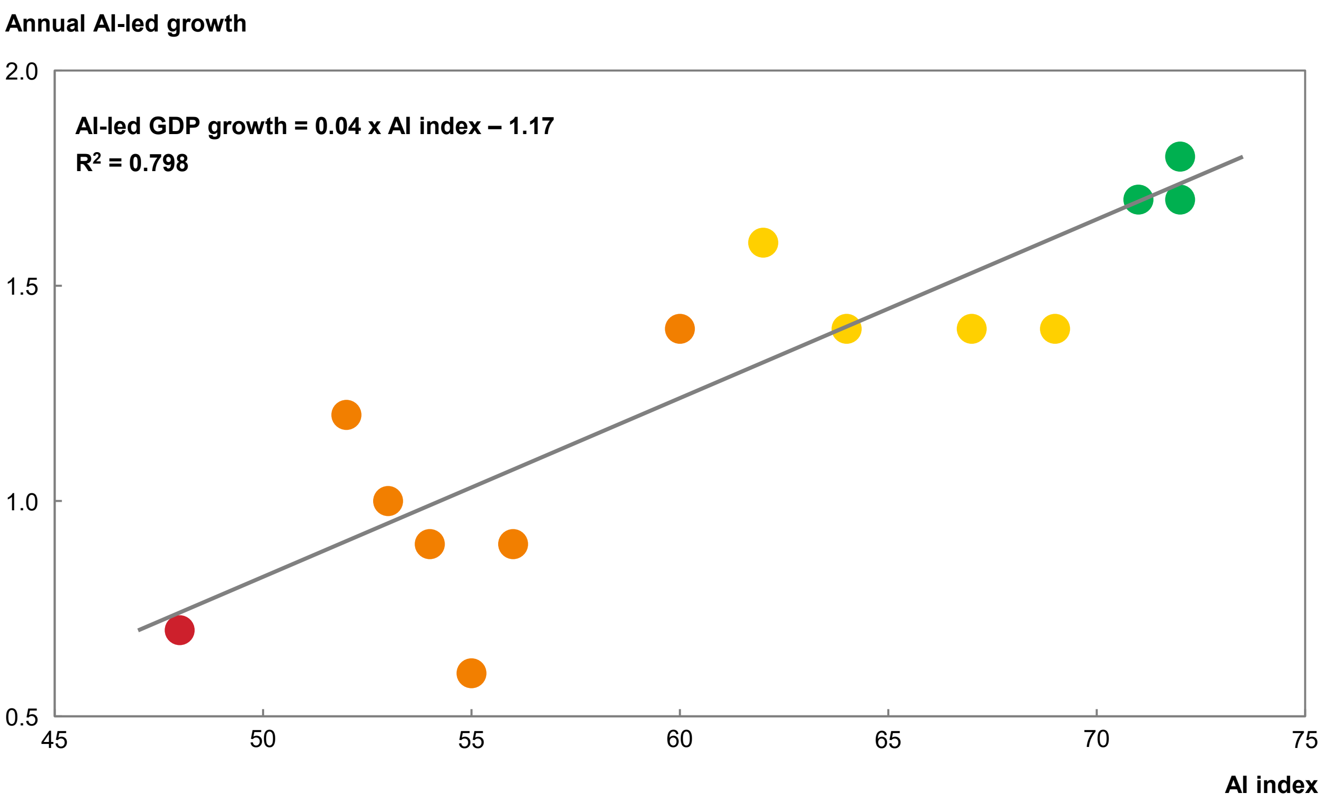
SOURCE: Eurostat; INSEAD; Directorate-General for Research and Innovation, European Commission; Programme for International Student Assessment (PISA); UNESCO; McKinsey Global Institute AI Diffusion Model; McKinsey Global Institute analysis

Exhibit 21

Better AI readiness leads to higher AI-led activity and employment growth.

%





SOURCE: McKinsey Global Institute analysis

5. EUROPE SHOULD CONSIDER PRIORITISING ACTION IN FIVE AREAS TO ACCELERATE ITS PATH TO AI

At the very least, Europe needs to develop its journey toward AI based on the enablers it already has and, therefore, its current readiness for AI. That may not be sufficient for a large number of European countries that may be at risk of exclusive growth, however. A more ambitious aim would be for Europe to try to close the gap with leaders such as the United States and China. Remember that these two world AI leaders may be forging ahead aggressively, and Europe runs a distinct risk of falling further behind in the race to AI and facing more competition for capturing growth and employment.[110] In the AI era, there is a risk that global competition will intensify and start to arbitrage jobs in services. As a case in point, today a higher proportion of Chinese and Indian software workers are filling job task requests on Amazon Mechanical Turk from US companies than the share of Chinese and Indian software workers who reside in the United States.[111]

If Europe fails to accelerate its adoption and diffusion of AI, it is likely to achieve only minimal productivity growth gains through the use of AI but may also fail to catch up with the United States and China.

We therefore foresee five priorities on which Europe should focus to strengthen enablers and become more AI-ready and to attempt to catch up with the world's AI leaders. We focus only on economic priorities and directly on digital AI-based technologies. Of course, Europe has other priorities that it needs to tackle, including, for instance, ensuring that the right enablers are in place to support the diffusion of AI. That includes the rapid rollout of more pervasive and high-load data infrastructures, such as 5G and edge computing in ICT networks or the development of a major footprint in other powerful disruptive technologies such as new advances in biology and engineering.[112] Europe also needs to develop an appropriate ethical framework for the inclusive and beneficial use of AI.[113] A framework for data use and ownership is also needed. On the latter, Europe has already hinted at giving citizens back power over their own data through the EU's General Data Protection Regulation (GDPR). Other projects, such as DECODE—in which citizens use digital wallets and general ledger technologies to provide improved user-generated rules covering who, how, and when data can be used—are powerful experiments from which to learn before they are potentially rolled out on a larger scale.[114]

Finally, the time has come for Europe to make a play in different areas of technology. The European Commission has already been playing a crucial role in allocating funding to boost technology development and diffusion, in creating a better playing field (through, for instance, the digital single market), and in developing new forms of regulation and protection, notably the GDPR. Now, the European Commission may want to pull some additional levers in the race to AI—for instance, initialising the AI market by ensuring that it and EU member states are major customers for these new technologies. The European Commission can also more actively support the development of a more robust network among city hubs to build scale and create new zones of regulatory sandboxes to foster experimentation.

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110 See, for example, "European scientists call for AI institute as US and China pull away", *Forbes,* April 24, 2018; and *Artificial intelligence: Implications for China,* McKinsey Global Institute, April 2017.

111 MGI analysis based on academic research on Mechanical Turk. See Aniket Kittur et al., "The future of crowd work", *Proceedings of the 2013 Conference on Computer Supported Cooperative Work,* 2013; and Joel Ross et al., *Who are the crowdworkers?: Shifting demographics in Amazon Mechanical Turk,* Conference on Human Factors in Computing Systems—Proceedings, 2010. Also see Richard Baldwin, *The globotics upheaval: Globalization, robotics, and the future of work,* New York, NY: Oxford University Press, February 1, 2019.

112 *Disruptive technologies: Advances that will transform life, business, and the global economy,* McKinsey Global Institute, May 2013.

113 *Notes from the AI frontier: Applying AI for social good,* McKinsey Global Institute, December 2018.

114 DECODE stands for decentralised citizen-owned data ecosystems and has been rolled out as part of smart-city projects in Amsterdam and Barcelona. For more, see Peter Sloly, *Safe, smart cities: Enormous potential but significant challenges,* Blue Line, October 27, 2018.

The five priorities discussed here are not only about doing more, but doing more rapidly and possibly in a different way.

Priority 1. Europe needs to continue developing a vibrant ecosystem of deep tech and AI startup firms that will use AI to create new business models

Besides ensuring that Europe has better control of its data and AI flows, there are three major economic reasons why Europe needs to develop its position more rapidly in the AI value chain to catch up with the world's AI leaders. First, if AI diffusion plays out as we simulate in our average scenario, investment in AI capital could increase at a double-digit growth rate, creating powerful revenue growth for the digital and ICT sector. That increase cannot be captured unless European countries have a strong digital- and AI-based ICT footprint.

Second, leaders in AI-based ICT have increasingly become platform based, creating major local ecosystems of smaller firms that will grow in the shadow of those platforms.[115] Third, these platforms are becoming global, generating large profits that could be repatriated to home headquarters and reinjected in the home economy, depending on tax incentives. Further, employment can be home biased. For instance, Google revenue from the United States was in the range of 45 percent in 2014, but the share of employees based in the United States was around 62 percent of the total workforce in the same year; Google engineers and headquarter-scale offices are concentrated in the United States.[116]

As discussed, within Europe are examples of successful AI development that economies can seek to emulate, particularly among Nordic countries. Finland and Sweden offer good examples. Sweden's capital, Stockholm, is one of the most prolific technology hubs in the world on a per capita basis. It has produced a remarkable number of new digital native companies and unicorns, often as a result of strong public-private partnerships. By 2013, Sweden was already home to about 250 deep tech firms—companies developing breakthrough technologies at the very frontier of data science, of which roughly 25 to 30 percent were AI-based startups. Entrepreneurship in digital tech has been vibrant in Finland's capital, Helsinki, which is home to internationally known companies such as Rovio, Supercell, and Linux. Helsinki has focused its technology portfolio on AI, biotech, and gaming and today has a per capita AI-startup density that is higher than in US benchmarks such as Boston, New York, or Seattle.[117]

Broadly, there are three ways to develop thriving AI-based ICT. The first is by public institutions being the first and the largest clients for new technologies. In general, EU member states have not been systematic in this regard, and the EU has not necessarily stimulated such activity. European e-governments remain scattered and incomplete, with the possible exception of the Baltic countries. China is a contrasting case in point. The government is enabling the development of AI by making it a national priority and is pulling on all levers, including R&D and skills development. Google's former chief of operations in China recently established a school to train more Chinese AI talent, which potentially could add almost 1,000 AI graduates a year.[118] Beyond funding, the Chinese government has become the main customer in AI ventures such as video recognition.

The second way to develop thriving AI-based ICT is by reinforcing early digital development, as the United States has done. The most digitally advanced countries often benefit from a strong digital ecosystem and a large digital sector that can create jobs locally and globally. According to our estimates in Europe, those ecosystems are largely built on agglomeration

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115 D. S. Evans, A. Hagiu, and R. Schmalensee, *Invisible engines: How software platforms drive innovation and transform industries,* Cambridge, MA: MIT Press, 2006.

116 The source for the first figure is Statista (https://www.statista.com/statistics/266250/regional-distribution-of-googles-revenue). The source for the second figure is Quora (https://www.quora.com/How-many-employees-does-Google-have-outside-the-US).

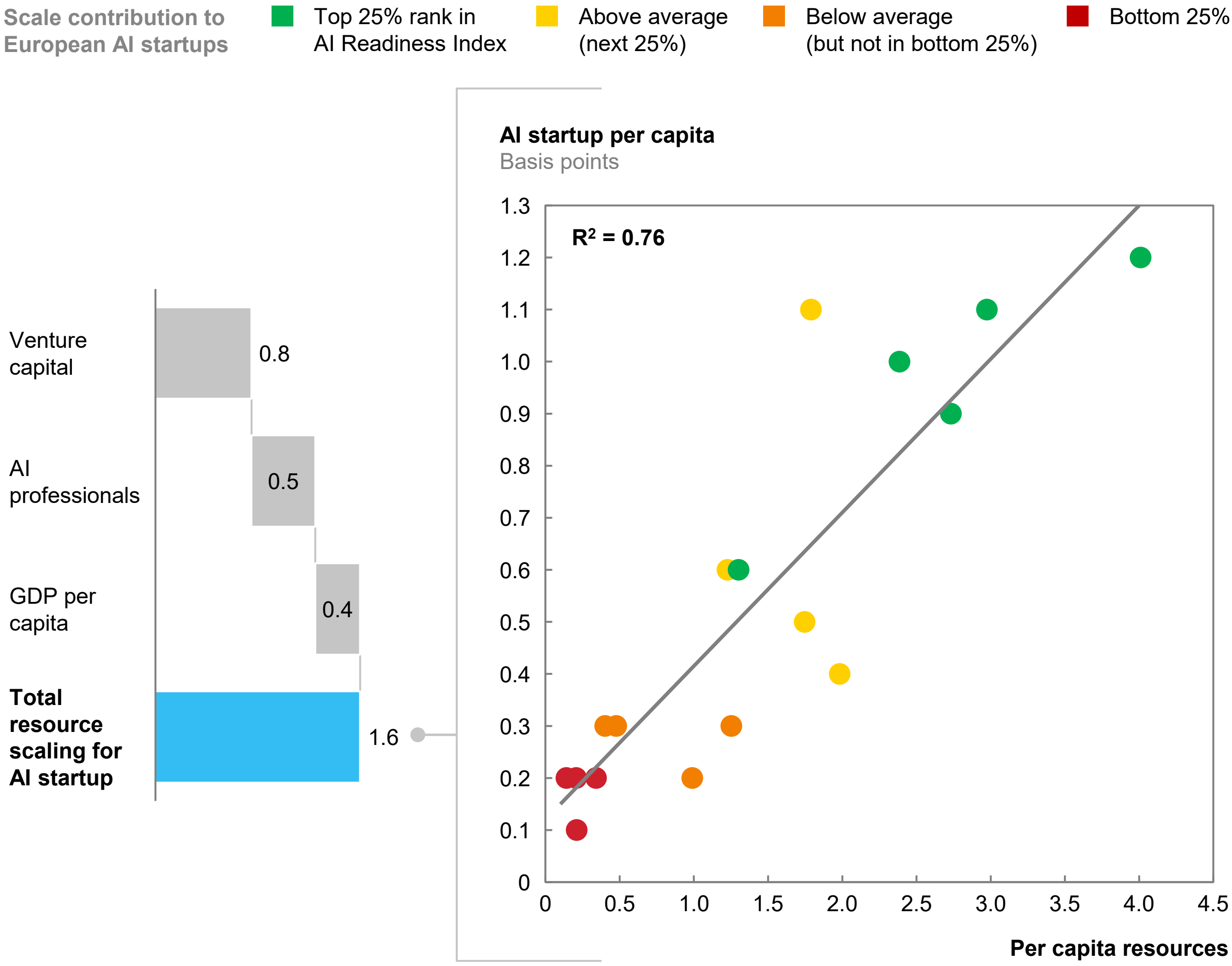
117 See *The top 50 best startup cities in the world,* Valuer+, Startup Genome, May 23, 2018 (https://valuer.ai/blog/top-50-best-startup-cities/).

118 Tom Simonite, "Ex-Google executive opens a school for AI with China's help", *Wired,* April 5, 2018.

and network effects (1.0 percent of additional mass leads to 1.6 percent of additional startup density), with a critical mass of end-to-end resources from universities to researchers and professional developers contributing 25 percent of total, financiers contributing 50 percent, and entrepreneurs eager to develop disruptive innovations 25 percent (Exhibit 22).[119]

Exhibit 22

Large economies of scale prevail in building AI ecosystems, which should include the right combination of venture capital and ICT professionals.



NOTE: In (AI startup per country) = 0.75 * In (venture capital) + 0.5 * In (professional developers) + 0.35 * (per capita GDP). Figures may not sum to 100% because of rounding.

SOURCE: Atomico; CB Insights; Eurostat; McKinsey Global Institute analysis

Despite Europe's success stories, the United States still invested double the capital in digital startups as Sweden between 2015 and 2017—and Sweden's investment was already double that of Finland and the United Kingdom. The United States has benefited from establishing clear university-industry funnels and industry clusters that are able to attract

119 Resource figures are based on a Cobb-Douglas function by which weights are estimated to find the best fit of predicting startup density by European country. Three factors play a significant role: deep tech finance (with a Cobb-Douglas exponent of 0.73), professional developers (0.27), and ability to build innovative business models (0.32). The statistics for the analysis have been extracted from the AI Genome project and from the EU's Directorate-General for Research and Innovation.

a disproportionate share of global venture capital. More than 50 US unicorns were founded by entrepreneurs emerging from Stanford and close to 40 from Harvard.[120]

Finally, although some hubs do deliver proof of concept, Europe also needs to find a way to create more than simply local economies of scale, linking thriving local hubs so that they can benefit from more global network effects. On many aspects, Europe currently appears to suffer from excessive fragmentation. Today, most European countries have developed their own AI road maps, but they suffer from two types of fragmentation: the allocation of resources does not happen Europe-wide and is therefore suboptimal, and project priorities do not fully overlap.[121] Clusters of AI excellence and innovation are dotted across the continent, and their number is growing; however, digital innovation hubs could benefit from forming a more dense network with each other. Today, European hubs are fragmented; the whole could be more powerful than the sum of its parts. A distributed and cooperating cluster of AI hubs across Europe (not a centralised hub) would be preferable, potentially relying on an EU-wide framework on legal expertise, data, funding, and incentives.[122]

Priority 2. Europe's incumbent firms need to accelerate their digital transformations and embrace innovating with AI

On top of building a new AI startup base and participating more in building the new ICT value chain, Europe's incumbent firms need to rapidly adopt and absorb AI to develop new and innovative business models. In the multiple surveys on AI we leverage for such work (see the technical appendix), we find that the share of European and US incumbent companies that want to couple digitisation with disruptive models is roughly the same (at about three of ten companies). The share of companies that have actually radically redesigned business models using AI, however, seems to be smaller in Europe than in the United States, at 4.6 percent and 8.2 percent, respectively. In Sweden, one of the most digitally advanced economies, 7.2 percent of companies say that they have fully morphed their business models.

Examples of firms that are doing so include automotive R&D leaders, such as BMW, which continue to account for a large portion of global R&D in the sector. BMW was already moving into virtual assistant technology in 2013; its "i Genius" enabled the company to engage with potential customers of its electric car.[123] BMW was quick to recognise that the game changer will be how automakers revolutionise self-driving cars, possibly integrating new service models such as "car-as-service." Although BMW quickly rolled out major new initiatives linked to AI, competition is rising from new players, such as Tesla Motors, which is playing at the intersection of electric cars and autonomous driving.[124]

Broadly, however, developing a culture amenable to digital-based breakthrough innovation is, in practice, difficult, especially for incumbents. Doing so tends to imply a cannibalisation of profit streams and major organisational changes. As we have discussed, though, the next wave of AI adoption could soon dampen revenue and profit growth for nonadopters. Bold, tightly integrated AI-based strategies are likely to be the biggest differentiators, whether by creating new digital businesses or by reinventing core businesses.[125] Incumbents need

[120] Christoph Kotsch, *Which factors determine the success or failure of startup companies? A startup ecosystem analysis of Hungary, Germany, and the US,* master's thesis, Andrássy Universität Budapest, diplom,de, July 25, 2017.

[121] The EU and its member states are aware of the issue. In April 2018, 24 countries signed a declaration of cooperation and mandated the EU to create a coordinated plan.

[122] Another issue is that the economics of agglomeration are present in Europe, with a large share of capital and imported talent going to larger hubs such as London. Brexit (the United Kingdom leaving the EU) may deepen the AI challenge for Europe.

[123] *Getting smarter by the day: How AI is elevating the performance of global companies,* TSC Global Trend Study, Part 1, Tata Consultancy Services, 2017.

[124] Bernard Marr, "How BMW uses artificial intelligence and big data to design and build cars of tomorrow, *Forbes,* August 1, 2017.

[125] Jacques Bughin, Laura LaBerge, and Anette Mellbye, "The case for digital reinvention", *McKinsey Quarterly,* February 2017.

to show foresight and display a willingness to respond boldly before their hand is forced. Established companies that recognise both the opportunities and the threats of automation to competitiveness will engage and embrace the potential that these technologies represent, prioritising a set of active experiments to start climbing the learning curves earlier rather than later. Eventually, they need to recognise when to reallocate resources to these new ventures and away from legacy operations. Furthermore, when incumbents lack the in-house capability to build new businesses, they must look to acquire them instead.[126]

In general, incumbents fail to recognise that digitisation enables them to develop much larger ecosystems than those defined in the past by their own industries. Digital technologies also enable broader servitisation or transformation. For instance, car manufacturers can now think about the driverless car as a new home for work and entertainment services, banks can host a retail marketplace, and healthcare companies can be more active in monitoring and connecting with patients.

European companies should start to develop such new opportunities, and European public-sector organisations can help to support experimentation. In Sweden, for instance, municipality-owned renovation agency Renova has teamed up with Volvo Trucks to test autonomous garbage trucks with the intention of increasing safety and optimising fuel consumption. e-Estonia carries a range of public services online, including access to healthcare data through KSI, an Estonian-developed blockchain technology.[127] Across Europe, we are beginning to witness the emergence of new types of industry alliance. One example is an alliance between the automotive and telecoms industries. Such collaborations across European borders can only be tested if cross-border activities are as smooth as possible, with, for instance, coordination of infrastructure, interoperability of systems, and the same regulation across Europe.[128]

Priority 3. Progress on the digital single market is continuing but still incomplete

Cross-border data flows are already contributing significantly to economic growth, and Europe has the potential to be the largest digital and AI market in size and value if it can remove the barriers that impede cross-border cooperation networks and achieve the free flow of cross-border data across the continent.

The European Commission launched its digital single market initiative in 2015, aiming to remove some online barriers and to form a more seamless digital marketplace, and announced a major investment in AI through its Horizon 2020 programme to connect AI research centres across Europe and develop an "AI-on-demand platform" that will provide access to relevant AI resources in the EU for all users. Regarding digital technology, the Commission has simplified value-added tax and improved laws regarding geo-blocking, roaming, and spectrum coordination. New regulations protect the EU-wide free flow of nonpersonal data via GDPR directives, and discussions about adopting a European cybersecurity framework are now in their latter stages.

Our recent research suggests that companies are happy with the official drive to develop a digital single market; however, to boost the digital single market, they still believe that a large part of the success will be improved execution.[129] We still see a perception among European deep tech entrepreneurs that regulation is a barrier to scaling up their businesses. One of the biggest advantages afforded by digitisation is scale, but Europe's digital and AI landscape

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126 Chris Bradley and Clayton O'Toole, "An incumbent's guide to digital disruption", *McKinsey Quarterly,* May 2016.

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

128 *European Automotive Telecom Alliance presents automated driving roadmap,* ERTICO—ITS Europe, February 27, 2017.

129 *European business: Overcoming uncertainty, strengthening recovery,* McKinsey Global Institute, May 2017.

remains fragmented in terms of telecoms networks, regulations, standards, and the logistics of e-commerce.[130] Enabling and encouraging telecoms providers to build more seamless cross-border, high-speed digital networks, together with the harmonisation of varied regulations, could remove some of the barriers to creating a regional ecosystem with bigger scale, at the same time ensuring that European privacy values are protected and that ethical and security concerns surrounding the development of AI are carefully addressed. Building a thoughtful framework for addressing data security, privacy, and potential issues of bias will be essential for a healthy AI ecosystem to thrive.[131]

The public sector has always supported the private sector by providing foundational infrastructure—and that continues to be the case as economies digitise. The necessary underpinnings include super-fast 5G networks, supercomputers, and quantum computing; however, Europe lags behind global leaders on these necessary foundations. China, the United States, and South Korea are acting faster to roll out the 5G networks that are needed to pave the way for autonomous vehicles.[132] Europe may also help support the pooling of resources—possibly with a pan-European dedicated infrastructure similar to DARPA in the United States—that would enable AI and machine learning to benefit from advances in quantum computing power and thereby enable the handling of much higher complexity and exponential growth in quantity of data. To get a sense of the magnitude of the advances happening elsewhere, consider that Google claims to have developed a quantum computer that can run operations 100 million times faster than any of today's systems.[133]

A final issue is that the digital single market focuses exclusively on tackling digital barriers, but nondigital barriers remain, too. A case in point is the prevalence of large home bias (trade between individual US states accounts for nearly 40 percent of GDP, whereas in the EU-28 the figure is half that). Europe has, to date, failed to tackle barriers to offline businesses going online, and, as a consequence, Europe's online cross-border share is lower than its offline share. Only 15 percent of EU consumers purchase online from other EU countries, and only 7 percent of Europe's small and medium-size businesses sell cross-border. Only 4 percent of the online services used in Europe are EU based and cross-border in scope; the vast majority are either US based or geared to their national market.[134]

Those barriers to offline-to-online are linked not only to specific policies but also to demand-side issues such as language and cultural differences. Evidence indicates that consumers lack both knowledge about their rights to cross-border transactions and trust in such transactions. Worries about data misuse seem to be an obstacle to a seamless European digital market. Long delivery times also seem to be an issue with many online European consumers.[135]

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[130] The need to take further steps is confirmed by the conclusions of the Tallinn Digital Summit held in September 2017, which stated that "completing the digital single market by 2018 is an important first step in realising these goals, but we should go further. We should review EU and national laws more broadly to make sure they are fit for the digital age. See *Preliminary conclusions of the Prime Minister of Estonia from the Tallinn Digital Summit 2017,* Tallinn Digital Summit, September 29, 2017.

[131] These are important issues but beyond the scope of this paper.

[132] The widespread use of autonomous cars will happen only through pervasive 5G networks that are needed to enable almost instantaneous course corrections. Local South Korean telecoms carriers, in cooperation with Samsung and Intel, are the most advanced in 5G trials of anywhere in the world. Europe has launched trials only in Stockholm. One issue is the coordination of auctions for spectrum among national regulators.

[133] Martin Giles and Will Knight, "Google thinks it's close to 'quantum supremacy.' Here's what that really means", *MIT Technology Review,* March 9, 2018.

[134] *Why we need a digital single market,* European Commission factsheet, May 6, 2015.

[135] Néstor Duch-Brown and Bertin Martens, *Barriers to cross-border ecommerce in the EU digital single market,* JRC Technical Papers, European Commission, 2015.

Priority 4. To capture the opportunity, companies need to build the right talent and skills

Recent MGI research on skill shifts suggested that a relatively large increase in demand for social, cognitive, and digital skills is likely to occur. Technology-centric talent is expected to see the highest increase in demand proportionately, increasing by an estimated 41 percent in Germany (or 6.5 percent of FTEs) and 66 percent in Spain (or 5.5 percent of FTEs) by 2030.[136]

The shift in demand presents two main challenges. First, skills that are in high demand are already in short supply—even at today's relatively low level of digitisation and AI adoption.[137] Second, the skill shift is likely to be two to three times larger than the shifts observed in the recent past.[138]

Obviously, the starting point for human skills tuned to AI and digital technologies is the right education. In higher education, Europe has some strengths. The United States outperforms Europe in numbers of top universities per capita, but Europe outperforms Asia on this metric currently, even including China. High-performing universities are not evenly distributed across Europe, however. Nordic countries have among the highest densities of high-performing universities, according to rankings from *The Times* and the Shanghai Ranking Consultancy, whereas Southern and Eastern Europe clearly lag behind.

In practice, the change needed in skills cannot wait for a full redesign of the education system—and in the short term, hiring new talent for firms on the scale needed is impractical; therefore, companies will need to be proactive about training and retraining their current employees. Although Europe today devotes more resources, in percent of its GDP, to training than do the United States and China, many employees of European firms—particularly small and medium-size enterprises—have limited access to training. Concerning new skills such as digital ICT, 30 percent of large enterprises still do not provide training, and that percentage rises to 80 percent in the case of small enterprises, defined as having between 10 and 49 employees.[139]

Some companies are turning to online training solutions, whereas others are providing their employees with subsidies to go back to school. In terms of high-end tech talent, some large companies are acquiring smaller tech and AI firms to gain an immediate infusion of expertise. AI itself provides valuable tools to aid in recruiting—including, for instance, neuroscience-based games that help to identify promising candidates who may have the right traits and innate talent, although they lack credentials.

In an age of rapid and continuous technological change, adaptability, learning how to learn, and entrepreneurship will be invaluable for the workforce, too. Because technical knowledge tends to become obsolete quickly, Europe needs to build opportunities for lifelong learning, particularly to help people who are already in the workforce reinvent themselves and gain new skills. Governments may help here. Skills Norway, the Norwegian agency for lifelong learning, offers individually adapted training in literacy, numeracy, ICT, and oral communication for adults. In Luxembourg, INFPC (the national institute for promoting vocational training) helps employers and employees structure skill paths, provides an overview of private programmes that offer skill upgrades, and partly funds that training through tax schemes. European policy makers might also look to Singapore, where the SkillsFuture programme grants about two million citizens around $345 each toward training courses provided by 500 approved institutions. The programme 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.[140] Policy

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[136] *Skill shift: Automation and the future of the workforce,* McKinsey Global Institute, May 2018.

[137] Gregory Lewis, *The most in-demand hard and soft skills of 2017,* LinkedIn, January 22, 2018.

[138] *Skill shift: Automation and the future of the workforce.*

[139] Sources for these data are Eurostat and OECD.

[140] *Digitally enabled automation and artificial intelligence: Shaping the future of work in Europe's digital front-runners,* McKinsey & Company, October 2017.

makers could also consider establishing tax-advantaged personal accounts for learning and retraining, with the government, companies, or individuals contributing.

AI itself could be a valuable tool to enable new forms of personalised learning. Digital technologies can support educational capacity, control costs, and boost quality. Virtual classrooms can increase the accessibility and scalability of lectures and allow for more personalised 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.[141]

Priority 5. Think boldly about how to guide societies through the potential disruption

At the same time as striving to catch up with the world's digital and AI leaders, European countries will need to manage the disruption to workers and to tackle rising inequality, which seems to be inevitable during the transition, as gaps appear between companies that adopt and those who don't (affecting their performance and therefore the number of people they can employ) and between workers with low and high skills.[142] Over the medium and longer term, every potential exists for a well-managed transition (including more resources) to lead to an improved employment situation and the redeployment of resources from lower-performing parts of European economies to higher-performing ones.

We have estimated the cost of tackling rising inequality—such as the cost associated with redeploying skills—and managing inequality (for instance, higher short-term unemployment). As noted, in Europe those costs reduce the potential for an additional €400 billion a year in gross value from AI to €250 billion a year. Those costs certainly reduce the returns to AI in the period covered by our analysis but do not "kill the case" for AI, whose positive effect will accelerate in the medium to long term. There is, however, a timing issue. The cost of AI is incurred before the benefits of AI kick in. The current crisis, compounded by the slow substitution of routine-based tasks, has already created some social pressure in many of the European countries, evidence of declining trust in institutions. Governments may be tempted to look for ways to slow the adoption of automation technologies, but such moves could prove counterproductive, holding back productivity without managing to save jobs in a lasting way.

During a period of adjustment, many workers may need assistance in the form of retraining or income support. If automation results in a significant reduction in employment or greater pressure on wages for some workers, Europe may need to reevaluate its social safety net. Some new ideas could be tested, including conditional transfers, different forms of taxation, or even universal basic income, as Finland and the Netherlands are currently doing. Denmark, for example, devotes roughly 1.5 percent of GDP to support the unemployed, with the lowest-paid workers receiving up to 90 percent of their former income. Swedish companies contribute to private job-security councils. If their workers are laid off, they receive financial support and job counseling to get them back into the workforce as soon as possible. As a result, Sweden leads the OECD in reemployment rates; some 85 percent of laid-off workers secure a new job within a year.

European labour markets may need greater mobility and better matching of talent with opportunity. In this respect, digital platforms can support those goals and also open up new opportunities for individuals to earn income outside or in addition to traditional employment contracts. Recent MGI research concluded that 20 to 30 percent of the working-age population has already spent time as independent workers, and just over half of this nontraditional workforce is engaged in independent work part time.[143]

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[141] 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.

[142] *Testing the resilience of Europe's inclusive growth model,* McKinsey Global Institute, December 2018.

[143] See *Independent work: Choice, necessity, and the gig economy,* McKinsey Global Institute, October 2016; and Jacques Bughin and Jan Mischke, *Exploding myths about the gig economy,* Vox EU, November 28, 2016.

Companies will also face competitive pressures to develop systems and processes to effectively manage a blend of traditional employees and independent workers, and the race will be on for technologists to innovate, finding new ways to connect individuals to paid work. Individuals will also face pressure to adapt. Independent workers will have to navigate the risks and challenges of nontraditional employment, particularly periods of income uncertainty, and learn to think of themselves as their own small business, finding ways for continuous improvement and skills development.

•••

Europe still suffers from a digital gap. Given that digital technologies are the bedrock of diffusion of AI technologies, the risk is that Europe could fall further behind the world's leaders on AI technologies and miss out on a significant source of potential new economic dynamism. We know that AI shares winner-takes-most characteristics with the previous wave of digital technologies, and that therefore there is an imperative for Europe to build on current strengths and pockets of best practice—and up its game. In short, Europe needs more AI, different AI, and all of it more quickly. This paper offers some brief thoughts on a road map of priorities that need to be in the mix.

TECHNICAL APPENDIX

This appendix presents the different surveys used for this report and presents more detail on the micro-econometric results and on the logic of our growth impact model from AI.

DATA SURVEYS: THREE INDEPENDENT SOURCES

Our analysis of AI must be based on a solid fact foundation to ensure that calibration is plausible. We support our research with three independent surveys, relying on common findings from all three.

VivaTech survey, March 2017

The first survey comes from the report prepared for VivaTech 2017.[144] For that event, MGI commissioned a global survey of C-suite executives in the spring of 2017, covering 10 countries and 14 sectors. The survey was commissioned externally from a major research firm and covered topics such as awareness and use of a set of AI technologies, returns to AI investment, impact on strategy, and workforce impact by skills and company functions. The survey contained about 25 questions. The average time to answer all of the questions was designed to be less than 20 minutes to maximise take-up rates and adequate responses. The survey was administered online.

We received 3,073 fully completed and validated sets of responses from an original sample of 20,000 firms. The responses were sorted to reflect both firm size (small, medium, large) and their sector's contribution in value added to each country's GDP. The answer rate was relatively good (more than 15 percent) from a total random sample of companies.

The ten countries surveyed were the United States, Canada, the five largest European countries and Sweden, China, and South Korea. Those countries were chosen because they are the largest contributors to world GDP, they are all digitally advanced, and all have scaled their investments in AI recently. The largest portion of answers came from the United Kingdom (12 percent), followed by the United States. The country with the fewest answers was Sweden (5 percent). Twenty-seven percent of responding firms were very small firms (with fewer than 10 employees), and 7 percent were firms with more than 10,000 employees. The sample covers service, agriculture, and industrial sectors.

The responses we received were tested for absence of bias. Specifically, we tested whether any differences appeared in our sample of answers with the original target of firms per sector or country, in terms of mean difference in key financial metrics of respondents and nonrespondents (revenue, revenue growth, profit, and profit growth). We used a simple one-way test per financial metric and a multivariate logit model of having answered or not, linked to all the financial metrics. We could not find statistical differences in answer rates. Finally, we tested for some self-reported biases. We randomised the order of questions for half of the sample and did not find any bias in types of responses. We checked for systematic responding (either extreme or only middle answers). We spotted 122 answers, or 4 percent of answers, regarding companies whose difference in answers by category on the questionnaire (AI awareness, AI impact on profit, AI impact on employment, and employment mix) were found to be very low (in the bottom 5 percent in difference for answers across all categories). The econometric results are not sensitive to whether or not those responses were included, however, so we kept our full sample as the basis of the survey.

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[144] *Artificial intelligence: The next digital frontier?* McKinsey Global Institute, June 2017.

European Business Summit members survey, April 2018

We decided to submit the same set of questions on AI adoption and impact at VivaTech to EBS members, as in our previous report on European business.[145] We sent the survey to a narrower list of companies that are members of the European Business Summit. In addition to the questions raised in our previous work, we added a few others related to how AI adoption could affect each company's hiring, mix of skills, and capital investment.

The survey was prepared for online encoding by EBS, which called on its members to complete the questionnaire. The number of responses to the questionnaire was slightly fewer than 100. Given the relatively small number, we use this survey only for illustrative purposes. Further, the sample covers only large companies from Europe, and we concentrated on the three largest European markets: the United Kingdom, France, and Germany. Because we knew the companies that were providing answers, we were able to match responses on financial metrics with reported ones, and we did not find statistically meaningful differences. Further, we tested three findings uncovered from the VivaTech data on the EBS data, and the two seemed to confirm each other:

1. **There is a size bias in AI adoption.** We first built two indices, the first for digital and the second for AI intensity, in which intensity is the proportion of digital technologies and AI that are used at scale by each corporation. We then ran the cross-section correlation with firm size (by number of employees). We found that the correlation with technology intensity is negative for companies with up to 1,000 employees and positive thereafter. This size-diffusion correlation effect is especially large for large companies with more than 10,000 employees ($r = 0.46$ for digital intensity and 0.26 for AI). The extent of the size bias is relatively close to what we found in the VivaTech sample of companies.

2. **Digital intensity drives AI diffusion.** The correlation between digital intensity and the adoption, pilot, and use of AI was found positive for each case, respectively, at $r = 0.47$; $r = 0.38$; $r = 0.32$.

3. **Uncertainty delays AI adoption.** We correlated firm AI intensity with firms' perceived AI business case and their perception that AI is already affecting their industry (versus little or not at all.) The first correlation is negative, $r = –0.1$, but not statistically significant. The second set of correlation demonstrates a positive correlation of $r = 0.49$ when the perception of AI impact is material and a negative correlation ($r = –0.18$ and $r = –0.15$) when the perception of AI impact is small or of no impact.

Those analyses run on the EBS sample demonstrate that the survey responses are broadly consistent with other early surveys and with economic logic. Because the sample is small, we aggregated the survey responses by country into our original VivaTech 2017 survey to serve as initial calibration of our European AI model. We use the current EBS survey for illustration and only when it concerns data that are strictly unique to the EBS survey.

McKinsey Digital Survey, June 2017

McKinsey has been collaborating with a major global independent research firm to develop and maintain a proprietary panel of executives from companies representative of the evolution of business around the world. The panel is maintained with care and is composed of more than 20,000 respondents. Typically, McKinsey will conduct four major surveys a year, via an online poll, with a typical response rate of between 1,500 and 2,500 firms. In 2016, a major survey was launched regarding digitisation, questioning how firms operate and how they revised strategy based on their adoption and diffusion of technologies. We used the same questionnaire poll that we used in 2017, but we added an explicit question regarding AI adoption tools so that we can look at the full trajectory of firms in their adoption of the full suite of digital technologies.

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[145] *European business: Overcoming uncertainty, strengthening recovery,* McKinsey Global Institute, May 2017.

We collected just over 1,600 responses from this survey. We analysed the survey results on adoption and tested them against the answers to the VivaTech survey, based on subcomparison by country or by industry. Tests of mean difference were made that demonstrated no statistical difference between the two samples except for two of 20 sectors analysed and two countries.

MICRO-ECONOMETRIC RESULTS

As part of MGI's micro-to-macro approach, we worked with a number of universities and with MGI economics specialists to develop econometric models of corporate diffusion of digital and AI technologies and the link between AI adoption, profitability, and further expansion in AI investment. Using either VivaTech or the Digital Survey panel, MGI found the systems of equations to provide statistically significant drivers of corporate diffusion. We found no real difference in relationship linked to the geographic locations of firms, so we used the global sample in our analysis to ensure the highest level of statistical relevance.[146] The analysis also logically explains the role of competitive dynamics in triggering AI adoption as a competitive response and the reasons certain companies do not expect to adopt AI in the near term.

Exhibit A1 synthesises the heat map of drivers of adoption and the diffusion of AI technologies. Those factors underscore the importance of previous investment in early digital technologies and the rivalry effect among others.

Exhibit A1

Heat map of influence of AI technologies on corporate absorption.

Impact on AI uptake[1] — ● High[1] ◉ Medium[1] ○ Low[1]

Dimensions	Advanced machine learning		Advanced robotics		Computer vision and language processing		Virtual assistants	
	Adoption[2]	Absorption[3]	Adoption[2]	Absorption[3]	Adoption[2]	Absorption[3]	Adoption[2]	Absorption[3]
Digital capabilities								
▪ Absorption cloud and big data	●				◉		○	
▪ Absorption mobile, internet, and web		○	○		◉		○	
AI complementarities	●	●	●		●	●	●	◉
Rivalry	●	●	●		◉		○	○
AI expected profitability	○	○	○	○	○	○	○	○

1 High = odd ratio >10; medium = odd ratio >3; low = odd ratio >1.
2 Adoption includes pilot, use cases not at scale, and all their cases of absorption at scale, either functional or across the whole enterprise; absorption is only adoption at scale across the whole enterprise.
3 Absorption intensity, or the ratio of absorption to adoption rate, as a measure of how adoption is scaled.

SOURCE: McKinsey Global Institute analysis

146 Country and industry effects are still controlled for in regressions. Asian companies tend to have lower adoption and diffusion propensities than those in Europe and the United States, but no broad difference exists between Europe and the United States. The exception is that Europe has a slightly higher propensity to diffuse advanced machine learning and to adopt robotics than does the United States, although that tendency is not visible in aggregate due to mix effects—early diffusion of AI is much higher in high-tech and advanced industries, which are much less prominent in Europe than in the United States. If those fixed effects offer only a limited explanation for the differences between the United States and Europe, this suggests that the difference in maturity between the two regions is more linked to the interplay of other factors. European companies seem to be less certain than their US counterparts about the returns that AI offers and are less advanced in rolling out early digital technologies.

The data also uncover solid clusters of firms, based especially on their attitude to adopt and on the type of focus and benefits expected from AI. Generally, those clusters are consistent with logic (for instance, faster adopters expect larger benefits) and with economic literature (one example of the latter is the finding that uncertainty delays diffusion, increasing the option value of waiting).[147]

Those relationships were then used to derive the dynamics of country diffusion and profit trajectory difference among firms by 2030; however, that approach also hinges on the hypothesis that current firm-level survey responses on attitudes and expectations will remain stable. Although expectations may not be realised, unaccounted-for factors may also have a significant effect on current reported attitudes and expectations. For that reason, this analysis is best seen as an attempt to calibrate AI trends.

Specifically, the econometrics modelling is based on the following steps.

- **Step 1.** The first step amounts to estimating a series of models and relationships at the firm level regarding both adoption of AI and its diffusion for each cluster of AI technologies (advanced machine learning, robotics and RPA, virtual assistants, and other tools, such as computer vision and language processing) via least squares regression techniques. The model is a logit model, in which the dependent variable is a binary (yes/no) variable regarding the state of adoption and diffusion of technology in full enterprise workflow. In addition to country and industry effects, the set of independent variables includes *capabilities and learning effects* (current stock of early digital technology in use, such as cloud, mobile, and web); *uncertainty of use case* (as measured by firms' perception of the business case of investing in AI); *state of competition* (rivals' adoption of AI); or *complementary effects* (for instance, adoption in other AI technologies to estimate the probability of AI diffusion by cluster).

  In general, this approach results in statistically robust relationships. Competition effects are rather strong for every type of AI technology, as are former digital capabilities. There are rather large signs of economies of scope (the more a company is invested in other AI technologies, the more it will invest in another AI tool). Of importance note is the importance of competitive rivalry, which will lead to major social contagion in the aggregate pattern of diffusion of AI.

- **Step 2.** The second step is to estimate a simultaneous model of profit growth and AI diffusion, using the logic that fast adoption relative to rivals will bring more profit potential, which improves the business case for AI and therefore further drives firms to adopt. This extra-step analysis uses 3SLS techniques, with industry and country effects and past profitability, as instruments. The profit growth equation is profit expectations over the next three years, which are made dependent on the past three years' profit growth (reflecting that profit dynamics are typically path dependent), and on AI diffusion and growth in AI investment. The analysis finds that the profit growth is path dependent; for example, one point of profit growth in the past three years induces 0.6 point of profit-growth expectation in the next three years. We also find a two-way relationship between AI diffusion and profit, ergo early diffusers experience a 15 to 20 percent uplift versus the average firm, and those profit expectations further boost diffusion, but only marginally, by 3 to 5 percent depending on the type of AI technology.

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147 See Massoud Karshenas and Paul L. Stoneman, "Rank, stock, order, and epidemic effects in the diffusion of new process technologies: An empirical model", *RAND Journal of Economics,* Volume 24, Number 4, Winter 1993; and Everett M. Rogers, *Diffusion of Innovations,* New York, NY: The Free Press, 1983.

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FURTHER READING

Atomico, *The state of European tech 2018,* 2018, https://2018.stateofeuropeantech.com/.

Bughin, Jacques, and Eric Hazan, "Five management strategies for getting the most from AI", *MIT Sloan Management Review,* September 2017.

European Commission, *Artificial intelligence: A European perspective,* December 2018.

Gregory, Terry, Anna Salomons, and Ulrich Zierahn, *Racing with or against the machine? Evidence from Europe,* ZEW discussion paper number 16-053, 2016.

McKinsey & Company, *Digitally enabled automation and artificial intelligence: Shaping the future of work in Europe's digital front-runners,* October 2017.

McKinsey Global Institute, *Notes from the AI frontier: Modeling the impact of AI on the world economy,* September 2018.

McKinsey Global Institute, *Superstars: The dynamics of firms, sectors, and cities leading the global economy,* October 2018.

McKinsey Global Institute, *Testing the resilience of Europe's inclusive growth model,* December 2018.

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