McKinsey Global Institute

Tech for Good

Smoothing disruption, improving well-being

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Summary

The development and adoption of advanced technologies including smart automation and artificial intelligence has the potential not only to raise productivity and GDP growth but also to improve well-being more broadly, including through healthier life and longevity and more leisure. To achieve these benefits—and reduce disruption and potentially destabilizing effects on society—will require an emphasis on innovation-led growth and careful management of the workforce and other transitions related to technology adoption and diffusion.

Technology has no overall purpose on its own; its effects are driven by human choices and actions. History is filled with examples of its potential both to do good and to cause harm: electricity brought substantial productivity gains, but also long transitions from agriculture to industry that were accompanied at times by stagnating real wages. Once-thriving manufacturing and mining towns have been depleted by the shift to a services-based economy.

How different will automation and AI be as they build on now-ubiquitous digital technologies? These technologies could displace some jobs but also improve work when technology is used to complement human capabilities. They could cause stress by increasing the intensity of work but also improve health and longevity if their uses include breakthroughs in personalized medicine and better disease prevention. Their deployment will require new skills but could also help make education more accessible. They consume large quantities of energy even as they help make homes, offices, and vehicles more fuel-efficient. Automation may bring heightened risks of unemployment and social change—and has already contributed to the wage polarization between high-skill and low-skill workers. Robotics deployed since the 1980s have raised productivity and changed the workplace, while at the same time creating new jobs elsewhere.

In short, technology will not improve lives on its own: it will need a development agenda for policy makers and business leaders that mitigates some of the downside effects of technology adoption, both in the short and longer term.

This discussion paper, the latest in our ongoing research on the impact of technology on business and society, is an attempt to understand both the positive and negative effects in more detail and to examine and evaluate ways in which new and mostly digital and smart technologies could potentially enhance welfare and soften disruptive transitions in advanced economies.

For the research, we compiled a library of about 600 use cases of technology applications that contribute to well-being, especially in relation to key societal challenges such as job security, health, and equal opportunities. More than 60 percent of these cases use some AI capabilities. We then developed a comprehensive welfare model of technology adoption that quantifies technology impacts beyond pure GDP. It incorporates critical dimensions of inequality, risk aversion to unemployment, leisure, and health and longevity, building on recent economic literature on welfare and well-being. Using this model, we conducted a simulation of welfare outcomes that enables us to compare the contribution of the new generation of technologies to previous generations and to identify key priorities for moving toward what we call a "Tech for better lives" outcome. Our preliminary insights from this exercise include the following:

— Technology is not intrinsically good or bad, but it can produce positive or negative outcomes—and often both—depending on how it is used. It affects different parts of the population unequally. In general, actions by business leaders and policy makers need to accompany technological innovations to ensure that the overall effects, and how they are distributed, create a positive balance.

— While technology adoption may be disruptive in the short term, especially to jobs and incomes, our library of applications (use cases) highlights a variety of ways in which technology itself can help smooth those disruptions and preempt risks. For example, online training programs and job-matching digital platforms can help workers improve skills and find employment, while mobile payments for financial access and online marketplaces that reduce prices of goods and services can positively affect material living standards. Other socially beneficial use cases include adaptive-learning applications to better prepare young people for the labor market, AI-powered drug discovery and personalized medicine for longer and healthier lives, and clean technologies for environmental sustainability.

— While technology has been a significant contributor to welfare growth in Europe and the United States in the past 40 years, our modeling suggests that, for the next decade, welfare growth may continue on the same trajectory only to the extent that new frontier technology adoption is focused on innovation-led growth rather than purely on labor reduction and cost savings through automation, and that technology diffusion is actively accompanied by transition management that increases workers' mobility and equips them with new skills. Other measures may also be needed to ensure a successful transition, potentially including support for wages. For all its potential, technology that enhances well-being is a tool kit that cannot address all the issues on its own.

— A first attempt to estimate the approximate monetary value of a scenario in which proactive management smooths transitions related to technology adoption and innovation-driven growth suggests that the potential boost to welfare—the sum of GDP and additional well-being components—can be between 0.5 and 1 percent per year in Europe and United States by 2030. This is as much as double the incremental growth from technology that we have modeled under an average scenario. Other scenarios that pay less heed to managing transitions or boosting innovation could slow income growth, increase unemployment risk, and lead to fewer improvements in leisure, health, and longevity.

— Government and business have important roles to play in ensuring good outcomes. The public sector can help drive innovation and improve welfare by supporting research and development including in health, spurring technology adoption through procurement practices and progressive regulation, and ensuring retraining and transition support for workers coping with workplace disruption. Business can focus technology deployment on new products, services, and markets, augment the skills of the workforce including with technological solutions, and increase worker mobility by creating new career paths, among other steps. They can also prioritize technology solutions that simultaneously improve their bottom line and the outcomes for society.

This paper is aimed at stimulating discussion about the opportunities and challenges surrounding technology adoption and how technology itself could help mitigate negative outcomes. This is a debated area of economics and policy. We hope our efforts and preliminary findings will stimulate other research in this field that will spur improvements in methodology and refine our insights. We intend to return to the issues raised in more detail in due course.

1. Technology, for better and for worse

Technology for centuries has both excited the human imagination and prompted fears about its effects. Philosophers and political economists from Plato to Karl Marx and Martin Heidegger have given technology a central role in worldviews that veer between benign optimism and despondent pessimism.[1]

Today's technology cycle is no different, provoking a broad spectrum of hopes and fears. At one end are the "techno-optimists" who emphasize the benefits to the economy and society, and at times promote theories of technology's "singularity," under which rapid growth in computing power and artificial intelligence accelerates sharply and brings a cascading series of improvements through the economy.[2] At the other end are "techno-pessimists," who worry about the potentially damaging consequences for society, particularly of AI, sometimes in apocalyptic terms.[3] Opinion surveys suggest people tend to have a nuanced view of technology but nonetheless worry about the risks: while generally positive about longer-term benefits, especially for health, a non-trivial proportion (between 15 and 25 percent) is also concerned about the immediate impact on their lives, in particular in the areas of job security, material living standards, safety, equal opportunities, and trust (Exhibit 1).

Intrinsically, technology is neither good nor bad—it is the use to which it is put that makes the difference. Malicious uses include mass disinformation campaigns and cyberattacks that seek to jeopardize national security, and cyberfraud targeting consumers.[4] Positive uses include AI applications for early detection and better treatment of cancer and other diseases that are a burden on society, such as diabetes.[5] Most technology applications can generate both good and bad outcomes—sometimes for the same person. While automation and other technologies may threaten some jobs and the material living standard of displaced workers, for example, these technologies can also be a source of new jobs and help people retrain and acquire new skills. They could also reduce the costs of basic goods and services for the same people as consumers.

This technological duality has always existed. Gutenberg's printing press could publish uplifting masterpieces of world literature and seditious pamphlets alike. A bolt of electricity can execute a convict on death row or light up a classroom in rural Africa. Strains of viruses can be used in germ warfare or to vaccinate children against diseases that would otherwise kill them.

1 Plato and Aristotle used technological imagery to express their belief in the rational design of the universe; for Karl Marx, technological advances were a key for his analysis of worker alienation under capitalism; Martin Heidegger's techno-pessimistic treatise *The Question Concerning Technology* (1954) emphasized that, while technology is not problematic in itself, human interaction with it is: "everywhere we remain unfree and chained to technology, whether we passionately affirm or deny it."

2 The notion of singularity is often attributed to mathematician John von Neumann and was popularized in the 1950s and '60s, including by Herbert Simon (*The Shape of Automation for Men and Management*, New York, NY: Harper and Row, 1965), and featured more recently in futuristic studies including Ray Kurzweil, *The Singularity Is Near: When Humans Transcend Biology*, London, UK: Penguin Books, 2005. For a detailed critique, see William D. Nordhaus, *Are we approaching an economic singularity? Information technology and the future of economic growth*, NBER working paper number 21547, September 2015.

3 For example, Stephen Hawking warned that "primitive forms of artificial intelligence we already have have proved very useful. But I think the development of full artificial intelligence could spell the end of the human race." "Stephen Hawking warns artificial intelligence could end mankind," BBC News, December 2, 2014.

4 Miles Brundage et al., *The malicious use of artificial intelligence: Forecasting, prevention, and mitigation*, Electronic Frontier Foundation, February 2018.

5 See, for example, Rob Matheson, "Artificial intelligence model 'learns' from patient data to make cancer treatment less toxic," MIT News, August 9, 2018; Ivan Contreras and Josep Vehi, "Artificial intelligence for diabetes management and decision support: Literature review," *Journal of Medical Internet Research*, May 30, 2018, Volume 20, Number 5.

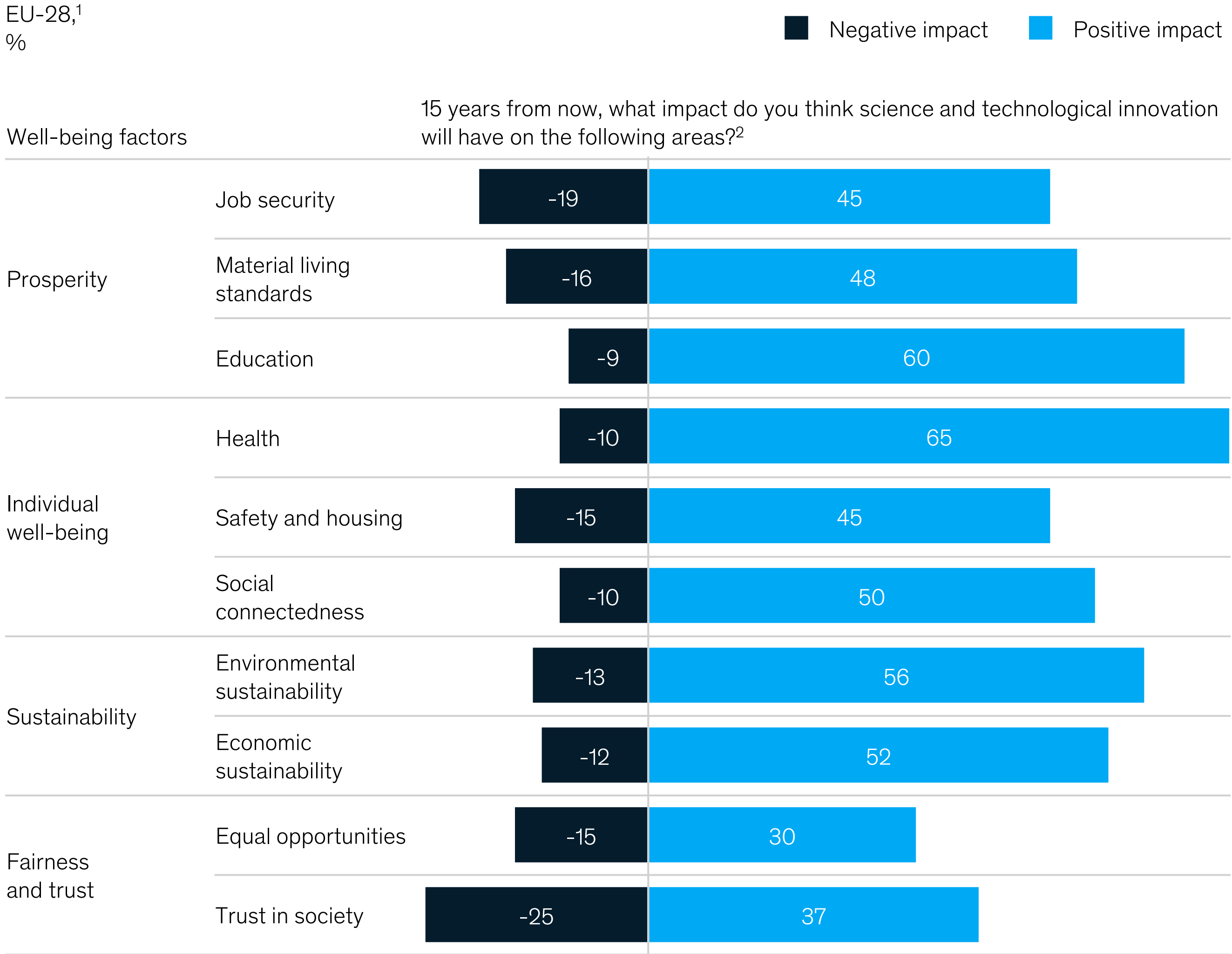
In our age, frontier technologies such as the Internet of Things, ledger technologies, smart robotics, automation, and artificial intelligence are likely to follow the same pattern. By boosting productivity growth, they will raise prosperity and replace mundane or dangerous tasks. They have the potential to do good across a wide range of domains, from healthcare to education. As in previous periods of technological innovation, these technologies may have perverse effects that will require preventive or counteraction, such as AI being used in warfare or unethically (see Box 1, “Ethics and frontier technologies: A burgeoning field of research and debate”). Other negative outcomes could include accelerated workforce dislocation, rising income inequality, and rising pressure on middle-class jobs that used to be abundant and relatively well paid.

That being said, technology has perhaps never been so present in our lives (Exhibit 2). Its ubiquity makes it an extremely powerful tool for delivering change, including change that is positive, if we want it to be.

Exhibit 1

People’s expectations of the future impact of technology are broadly positive, but with particular concerns around jobs, wages, safety, equality, and trust.

EU-28,[1]
%



[1] Austria, Belgium, Bulgaria, Croatia, Cyprus, Czech Republic, Denmark, Estonia, Finland, France, Germany, Greece, Hungary, Ireland, Italy, Latvia, Lithuania, Luxembourg, Malta, Netherlands, Poland, Portugal, Romania, Slovakia, Slovenia, Spain, Sweden, United Kingdom.
[2] Questions mapped to the MGI societal well-being framework. Survey with 27,910 respondents across the 28 European Union countries, representative of the European Union population.

Source: *Special Eurobarometer 419, Public perceptions of science, research and innovation*, 2014; McKinsey Global Institute analysis

Box 1

Ethics and frontier technologies: A burgeoning field of research and debate

The rapid recent progress in AI and other frontier technologies means that cars that drive themselves, AI-powered mass surveillance systems, autonomous weapons, and other smart applications that can affect human life—potentially catastrophically—are no longer science fiction but a new reality. At the same time, we are increasingly using algorithms as tools to make decisions in highly sensitive areas, including hiring, criminal justice, and healthcare, sometimes without fully understanding how these algorithms reach their conclusions.

These developments have sparked growing debate about the ethics of this new technological era: Can we teach machines to "behave" according to accepted human ethical norms—and if so, what are those norms in a world with such a variety of cultures and values? How do we counteract bias in algorithms that are trained on data sets that largely reflect our own human bias? And what should business and government do to draw the line between right and wrong in a machine learning world?

Academic researchers, business and government leaders, and technical professional bodies are all looking carefully at the social uses and potential abuses of AI. In recent months, donors including technology company executives have stepped up funding for major programs, including at MIT's Media Lab, Harvard's Berkman Klein Center for Internet and Society, Stanford University, and the University of Toronto, to study the implications of AI, including how it will affect people's lives and serve humanity.[1] International organizations such as the European Commission and the UN's International Telecommunication Union have created working groups and frameworks for "trustworthy" AI and its ethical use.[2] Individual governments are increasingly issuing their own white papers and guidelines, even as they outline national AI research and development programs.[3]

Identifying problems and flashpoints is an essential first step—and the exercise can at times hold up a mirror to human failings. The issue of bias and fairness is one example. Algorithms can embed human and societal biases and deploy them at scale; for example, an analysis by ProPublica of scores used to predict future criminal activity in Broward County, Florida, showed that algorithms were nearly twice as likely to incorrectly label African-American defendants as higher risk as to incorrectly label white defendants.[4] Researchers at MIT have found that error rates in facial analysis technologies differed by race and gender—with a much higher error rate for black women than for white men.[5] Yet these failings largely are the fault of biases existing in society and reflected in the historical data used to train the algorithms. In many cases, AI can actually reduce humans' subjective interpretation of data, as machine learning algorithms learn to consider only the variables that improve their predictive accuracy. To quote Andrew McAfee of MIT, "If you want the bias out, get the algorithms in."[6]

Beyond the theoretical discussion, and harder still, is the practical application of ethical decisions. How do we ensure that AI outputs are fair; that new levels of personalization do not translate into discrimination; that data acquisition and use do not sacrifice individuals' privacy; and that organizations balance transparency about how decisions are made with the performance benefits of AI? Already, this new era is shaping up as a busy one for professional philosophers.

1 Steve Lohr, "MIT plans college for artificial intelligence, backed by $1 billion," *New York Times*, October 15, 2018; Maria Di Mento, "Donors pour $583 million into artificial intelligence programs and research," *Chronicle of Philanthropy*, October 15, 2018. MIT and Harvard launched a joint initiative on the ethics and governance of AI topics in 2017; see aiethicsinitiative.org.

2 See *Ethics guidelines for trustworthy AI*, European Commission, High-level working group, 2018; *How to prevent discriminatory outcomes in machine learning*, World Economic Forum, March 12, 2018; Kyarash Shahriari and Mana Shahriari, *IEEE standard review—Ethically aligned design: A vision for prioritizing human well-being with artificial intelligence and autonomous systems*, IEEE Canada International Humanitarian Technology Conference, Toronto, Canada, July 21–22, 2017.

3 For a list of European AI initiatives, see "Artificial intelligence: European R&D strategies," European Space Agency blog, January 11, 2019, blogs.esa.int/philab/2019/01/11/european-artificial-intelligence-rd-strategies/.

4 Julia Angwin et al., "Machine bias," ProPublica, May 2016

5 Joy Buolamwini and Timnit Gebru, "Gender shades: Intersectional accuracy disparities in commercial gender classification," *Proceedings of Machine Learning Research*, 2018.

6 Eric Rosenbaum, "Silicon Valley is stumped: Even A.I. cannot always remove bias from hiring," CNBC, May 30, 2018.

Technology can bring substantial welfare benefits, including economic growth and better health

Accompanying and underlying the broad discussion on ethical boundaries for AI is anxiety about technology's potential disruption with negative outcomes for well-being. This can lead to risk aversion, which in itself can have significant adverse effects.[6]

At the same time, technological innovations over the ages have brought major welfare gains in the form of better and longer life as well as higher incomes and extended leisure (see Box 2, "What we mean by welfare and well-being"). In 1870, in the era of the steam engine and the telegraph, life expectancy at birth was 40 years in the United States and 36 years in Europe. If they made it to adulthood, the average worker in the United States spent more than 60 hours on the job every week, for a relatively modest income.[7] By 1970, life expectancy at birth had more than doubled, US citizens' revenue per capita was almost ten times higher, and the workweek had fallen below 45 hours a week. In Germany, the printing and metal workers' union in 1995 negotiated the introduction of the 35-hour workweek. Today, no country in the world has a lower life expectancy than the countries with the highest life expectancy in 1800 (Exhibit 3).[8]

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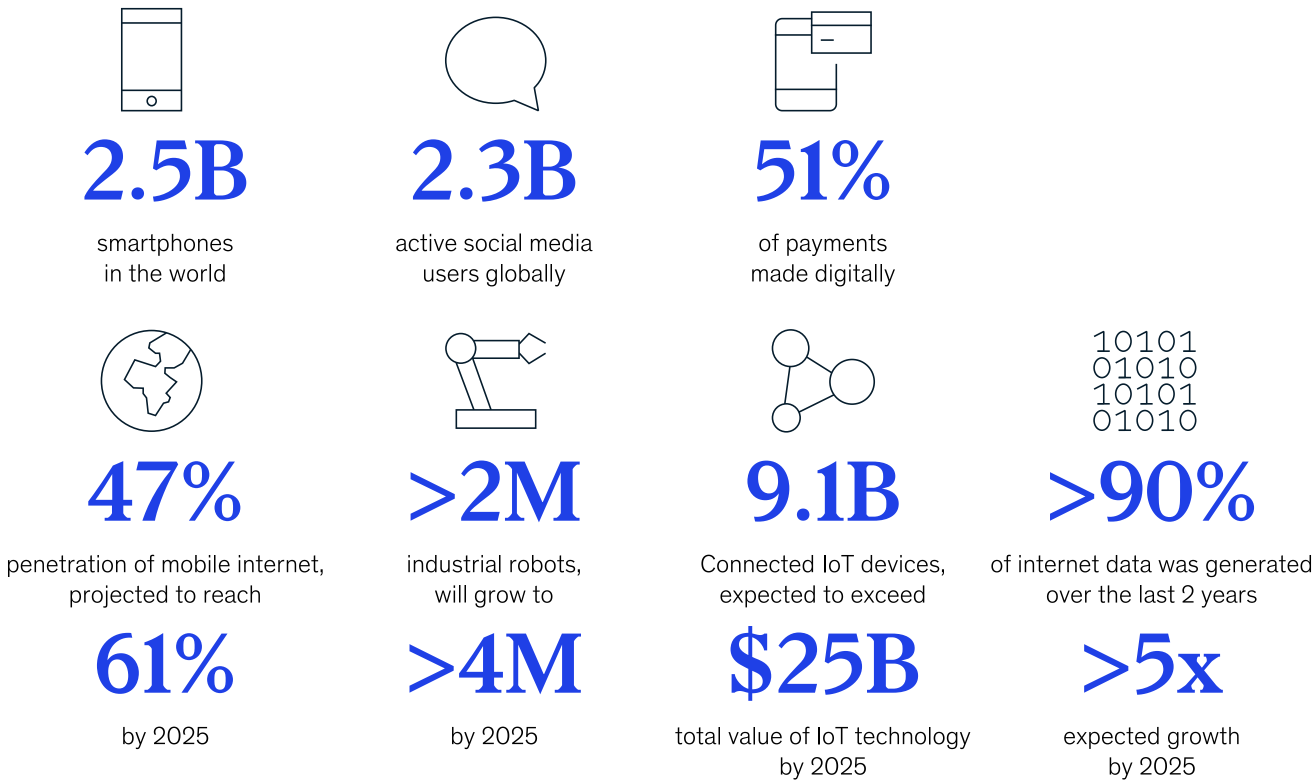
[6] Economists have long recognized that risk aversion can have a negative effect on individuals' utility or firm profit. In general, they model uncertainty using an expected utility framework, in which utility, or profit, is reduced by the amount of risk aversion attached to uncertain events. A typical metric of this risk is the Arrow-Pratt measure, which is directly related to the variance in outcomes linked to the distribution of uncertainty. The finance literature looks at covariance of outcomes as systematic risk or beta; the welfare literature we leverage in this research uses a standard measure of variance. We apply this measure to estimate the negative welfare consequences of consumption inequality and of risk of unemployment. See John W. Pratt, "Risk aversion in the small and in the large," *Econometrica*, January–April 1964, Volume 32, Number 1–2, and Kenneth Arrow, "Aspects of the theory of risk bearing," in *Essays in the Theory of Risk Bearing*, Chicago, IL: Markham Publishing Co., 1971. See also Daniel Kahneman and Amos Tversky, "Prospect theory: An analysis of decision under risk," *Econometrica*, 1979, Volume 47, Number 2.

[7] Robert Whaples, *Hours of work in US history*, Economic History Association, eh.net/encyclopedia/hours-of-work-in-u-s-history/.

[8] Max Roser, *Our world in data*, ourworldindata.org/life-expectancy.

Exhibit 2

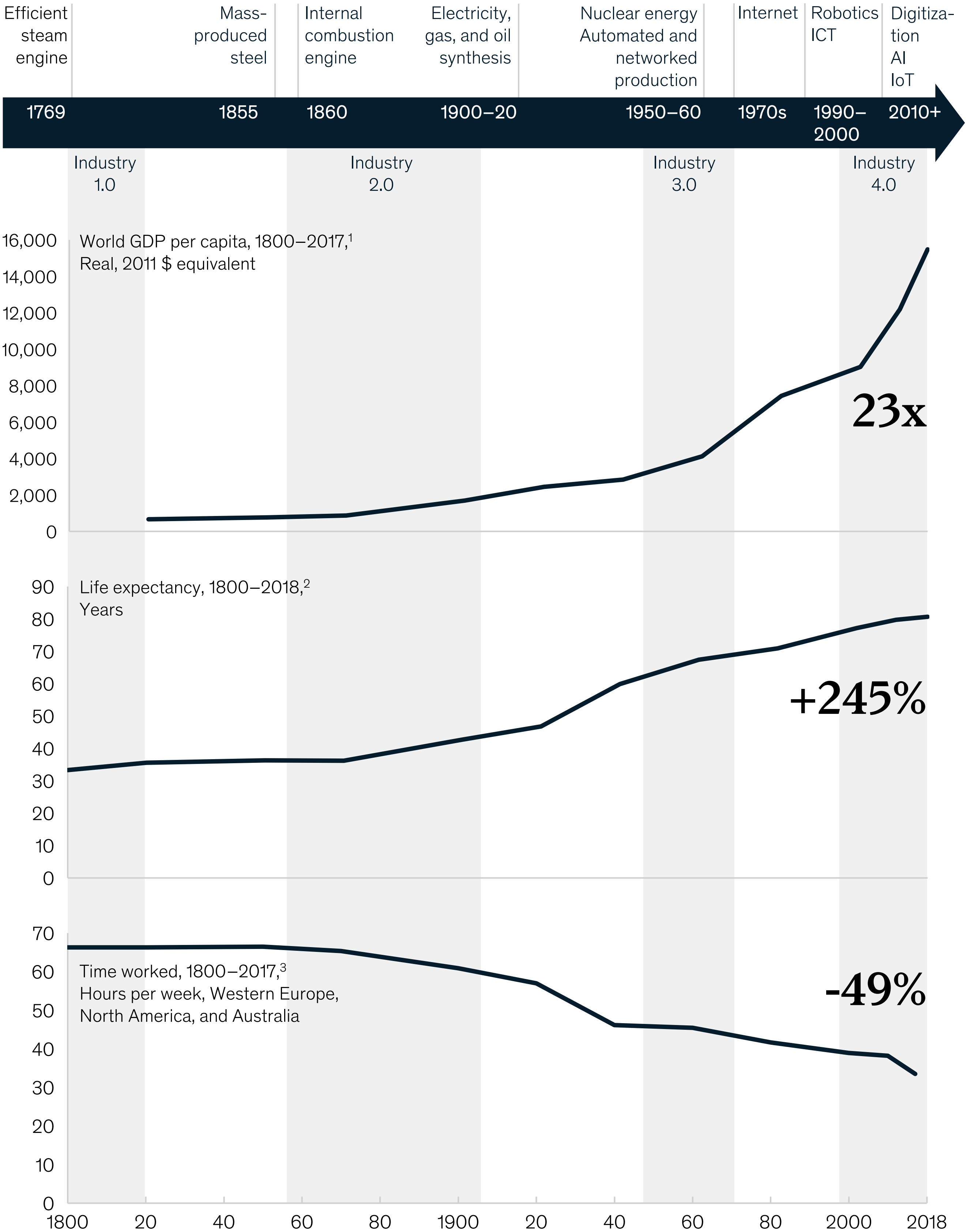
Technology permeates every aspect of society and is an important instrument of change.



Source: *Why digital strategies fail,* McKinsey & Company, March 2018; GSMA 2019; Domo; IDC; McKinsey Global Institute analysis

Exhibit 3

Growth and life expectancy have improved as hours worked have fallen since 1800.



1 Maddison Project database 2018; World Bank; McKinsey Global Institute analysis.

2 Data until 1990: James C. Riley, "Estimates of regional and global life expectancy 1800–2001," *Population and Development Review*, Volume 31, Issue 3, September 2005. Data 2000 and later: WHO, World Bank, assembled by Max Roser.

3 Data before 1870 from the United Kingdom only. For 1870—2000, data are an average of Australia, Canada, Denmark, France, Germany, Ireland, Italy, Netherlands, Sweden, United Kingdom, and United States. Bank of England; OECD; Michael Huberman and Chris Minns, "The times they are not changin': Days and hours of work in Old and New Worlds, 1870–2000," *Explorations in Economic History*, July 2007; McKinsey Global Institute analysis.

Source: McKinsey Global Institute analysis

Box 2
What we mean by welfare and well-being

Welfare is an economic concept that goes beyond GDP. It incorporates more nuanced aspects of the population and the economy, such as consumption and inequality, and includes additional components, such as life expectancy and leisure, that affect the well-being of individuals and societies. Welfare can be quantified in GDP-equivalent terms. In this paper, total welfare refers to GDP plus non-GDP welfare components. When discussing less monetary and broader effects, we refer to well-being. For more detail, see chapter 2.

More recent health metrics provide powerful examples: the survival prospect for a teenager diagnosed with type 1 diabetes in the early 1900s was barely two years; today, thanks in part to insulin technology and greatly improved healthcare and nutrition, among other factors, the gap in remaining life expectancy between a teenager with diabetes and one without has declined from 52 to 17 years.[9] AI's uses in medicine promise new improvements in health outcomes, at a time when pharmaceutical companies are suffering declining returns to their R&D investment.[10] Among the most promising: researchers at the MIT Media Lab have applied some AI capabilities in clinical trials to successfully reduce the toxic chemotherapy and radiotherapy doses given to patients with some types of brain cancer. Google's DeepMind recently demonstrated a device that can conduct real-time diagnoses of complex eye diseases.[11] Adopting the latest technology in healthcare can be costly, but research tends to suggest that the social value of longer and better life can be an order of magnitude greater than the cost.[12]

Rising productivity from technology has historically been accompanied by wage and employment growth, which in turn boosts prosperity. This is because the higher productivity achieved through technology adoption increases incomes of workers and shareholders.[13] Higher incomes are spent, which creates demand for goods and services across the economy, and new demand for labor.[14] Moreover, technological innovations can greatly reduce prices and increase the quality of goods and services.

One example is the Ford Model T automobile. Its process innovation dramatically improved productivity with the introduction of the assembly line. This almost tripled the number of Model Ts produced per worker annually, enabling Ford to reduce prices, from $950 in 1909 to $440 in 1915. This in turn helped raise sales 40-fold and boost employment from 1,655 to 18,892 in the same period.[15] Another example is the personal computer, whose introduction starting in the 1970s made jobs such as typists largely obsolete but created entirely new occupations including software developers and call center customer service representatives.

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9 Katarina Steen Carlsson and Bengt Jönsson, "Valuing new medicines in the early 21st century," *Nordic Journal of Health Economics*, 2017, Volume 5, Issue 1.

10 Ish Khanna, "Drug discovery in pharmaceutical industry: Productivity challenges and trends," *Drug Discovery Today*, May 22, 2012.

11 Rob Matheson, "Artificial intelligence model 'learns' from patient data to make cancer treatment less toxic," MIT News, August 9, 2018, news.mit.edu/2018/artificial-intelligence-model-learns-patient-data-cancer-treatment-less-toxic-0810; Madhumita Murgia, "Artificial intelligence group DeepMind readies first commercial product," *Financial Times*, March 30, 2019. For more examples, see *Notes from the AI frontier: Applying AI for social good*, McKinsey Global Institute, October 2018.

12 This depends on the exact health problem and treatment in question; see, for example, Peter Abelson, "The value of life and health for public policy," *The Economic Record*, June 2003, Volume 79; and Kevin M. Murphy and Robert H. Topel, "The value of health and longevity," *Journal of Political Economy*, 2006, Volume 114, Issue 5.

13 James Bessen showed that productivity-enhancing technology will increase industry employment if product demand is sufficiently elastic. James Bessen, *Automation and jobs: when technology boosts employment*, Boston University School of Law, 2017.

14 David Autor and Anna Salomons, "Does productivity growth threaten employment?," European Central Bank Forum on Central Banking, Sintra, Portugal, June 17–19, 2017.

15 David Hounshell, *From the American System to Mass Production, 1800–1932: The Development of Manufacturing Technology in the United States*, Baltimore, MD: The Johns Hopkins University Press, 1985; David H. Autor, "Why are there still so many jobs? The history and future of workplace automation," *Journal of Economic Perspectives*, Summer 2015, Volume 29, Number 3.

It also changed many jobs, including those of bookkeepers, stock clerks, and personal assistants. In all, we estimate that the PC destroyed some 3.5 million jobs in the United States between 1970 and 2015 but created at least 19.3 million new ones, a net gain of 15.8 million—equivalent to 10 percent of the US civilian labor force in 2015.[16]

This dynamic of innovation boosting productivity, which raises employment, sometimes resembles a virtuous cycle of growth. It is the reason that aggregate employment has grown over the long term, even as technology has transformed production and the workforce has expanded.

Intentionally slowing down technology diffusion could therefore be counterproductive. History shows that countries at the forefront of technological progress tend to be more successful than others. One simulation we conducted showed that AI adoption could raise global GDP by as much as $13 trillion by 2030, or by more than 1 percent additional GDP growth per year, assuming retraining and mobility to ensure adequate matching of talents in the workforce to shifting demand patterns.[17] The same simulation showed that resisting the diffusion of AI and digital technologies could lead to negative incremental GDP growth as a result of competitive disruption.[18] Over time, resisting technology may also increase the risk of unemployment and hence increase inequality, as unemployment disproportionately affects lower-skill workers.[19]

Technology transitions create risks and disruption that need to be managed

The impact of technology on welfare is an even more complex topic than its impact on GDP growth. Some technology applications are high risk and need to be managed to avoid harm; AI, to take an example, may also have lethal uses including warfare. As highlighted in Box 1, adopting new technologies safely therefore requires some basic rules of ethics. Besides obvious cases of the need for careful prospective prevention, more prosaic negative cases may also prevail. For example, technology can boost labor productivity but also make work environments more intense and, in some cases, lead to high levels of stress.[20]

In previous research, we have documented how technologies have played a central role in raising economic productivity, even if the adoption of these technologies at times caused large-scale structural transformations that led to worker dislocation.[21] In the United States, mechanization during the Industrial Revolution followed by a shift to service industries brought the agriculture share of employment down from 58 percent of total employment in 1850 to 2.5 percent of employment today. China's more recent shifting sector mix has been especially rapid: agricultural employment has fallen as a share of total employment by 32 percentage points in just 25 years, from 60 percent in 1990 to 28 percent in 2015.[22] Data from the United Kingdom show that productivity growth has been associated with reduced employment growth within specific sectors and regions, even where it is associated with increases in employment overall (Exhibit 4).

At times, these shifts have taken a severe toll on the labor market. While economic theory suggests that real wages should grow in line with labor productivity, this process may be long. In England, the heartland of the first industrial revolution, real wages stagnated for roughly 50 years, from 1790 to 1840, when the steam engine and other technologies increased the productivity of unskilled workers and enabled them to undertake work previously carried out by higher-skill, higher-paid craftsmen and artisans. During this period, profits as a share of national income rose and the labor share of income declined; the phenomenon, first noted by economist Friedrich Engels in 1845, is often referred to as "Engels' pause."[23] Besides a possible wage gap,

16 *Jobs lost, jobs gained: Workforce transitions in a time of automation*, McKinsey Global Institute, December 2017.
17 *Notes from the AI frontier: Modeling the impact of AI on the world economy*, McKinsey Global Institute, September 2018.
18 Jacques Bughin, "Why AI isn't the death of jobs," *MIT Sloan Management Review*, Fall 2018.
19 See *Testing the resilience of Europe's inclusive growth model*, McKinsey Global Institute, November 2018.
20 Victor Lipman, "Workplace trend: Stress is on the rise," *Forbes*, January 9, 2019.
21 The productivity effects can sometimes take years to show up in official statistics, however. See *Jobs lost, jobs gained: Workforce transitions in a time of automation*, McKinsey Global Institute, December 2017.
22 Groningen Growth and Development Centre 10-Sector Database.
23 Robert Allen, "Engels' pause: Technical change, capital accumulation, and inequality in the British Industrial Revolution," *Explorations in Economic History*, October 2009, Volume 46, Issue 4.

another risk is friction in the reallocation of labor resources. Multiple studies including by Joseph Schumpeter and David Ricardo have shown that technology can create unemployment for at least a few years before the labor market adjusts to technological shocks.[24]

More recently, digitization of the economy and the rise of automation have contributed to income polarization between high-skill and low-skill workers and put wage and employment pressure on the middle class (Exhibit 5). According to one US study, every additional robot per thousand workers that is deployed reduced the employment-to-population ratio by about 0.18 to 0.34 percentage point and wages by 0.25 to 0.5 percent.[25] Technology-induced unemployment tends to disproportionately affect lower-skill workers: unemployment rates between skilled and unskilled labor widen initially, but then decline after a roughly five-year lag, as training, learning, and rehiring take place.[26] This is a long period for those affected by unemployment risk, and potentially devastating for those who are nearing the end of their working life or unable to be redeployed.

Many people are feeling squeezed—and the data support their impressions. We previously found that 65 to 70 percent of households in advanced economies were in segments of the income distribution whose real market incomes had fallen in 2014 compared with 2005. That's the equivalent of 540 million to 580 million people.[27]

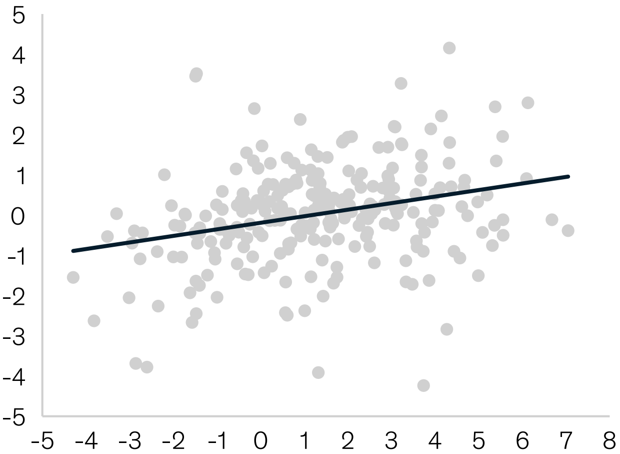
[24] Jacob Mincer and Stephan Danninger, *Technology, unemployment, and inflation*, National Bureau of Economic Research working paper number 7817, July 2000. Joseph A. Schumpeter, *The theory of economic development: An inquiry into profits, capital, credit, interest and the business cycle*, 1911.
[25] Daron Acemoglu and Pascual Restrepo, *Robots and jobs: Evidence from US labor markets*, National Bureau of Economic Research working paper number 23285, March 2017.
[26] Jacob Mincer and Stephan Danninger, *Technology, unemployment, and inflation*, National Bureau of Economic Research working paper number 7817, July 2000.
[27] *Poorer than their parents? Flat and falling incomes in advanced economies*, McKinsey Global Institute, July 2016.

Exhibit 4

Productivity and employment tend to grow hand-in-hand at the aggregate level, but with significant local and sectoral transitions.

Productivity and employment in the UK, 1760–2016[1]

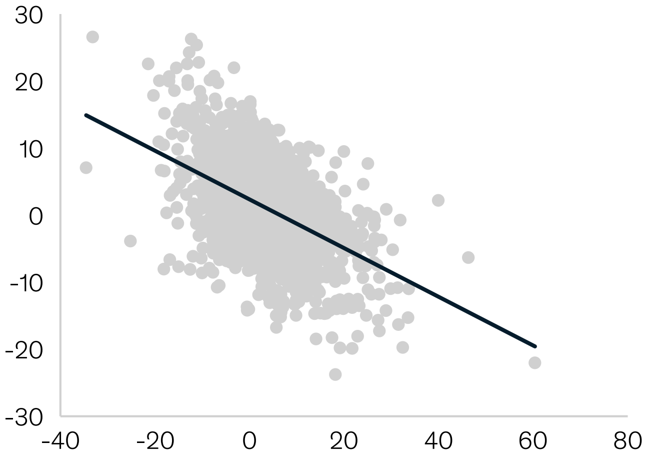
Employment rate change,
Year on year change, % of total workforce



Productivity growth,
Year on year change, %

Productivity and employment in 180 sector/region combinations in the UK, 1997–2016[2]

Employment change,
Year on year change in total employment, %



Productivity growth,
Year on year change in gross value added per job, %

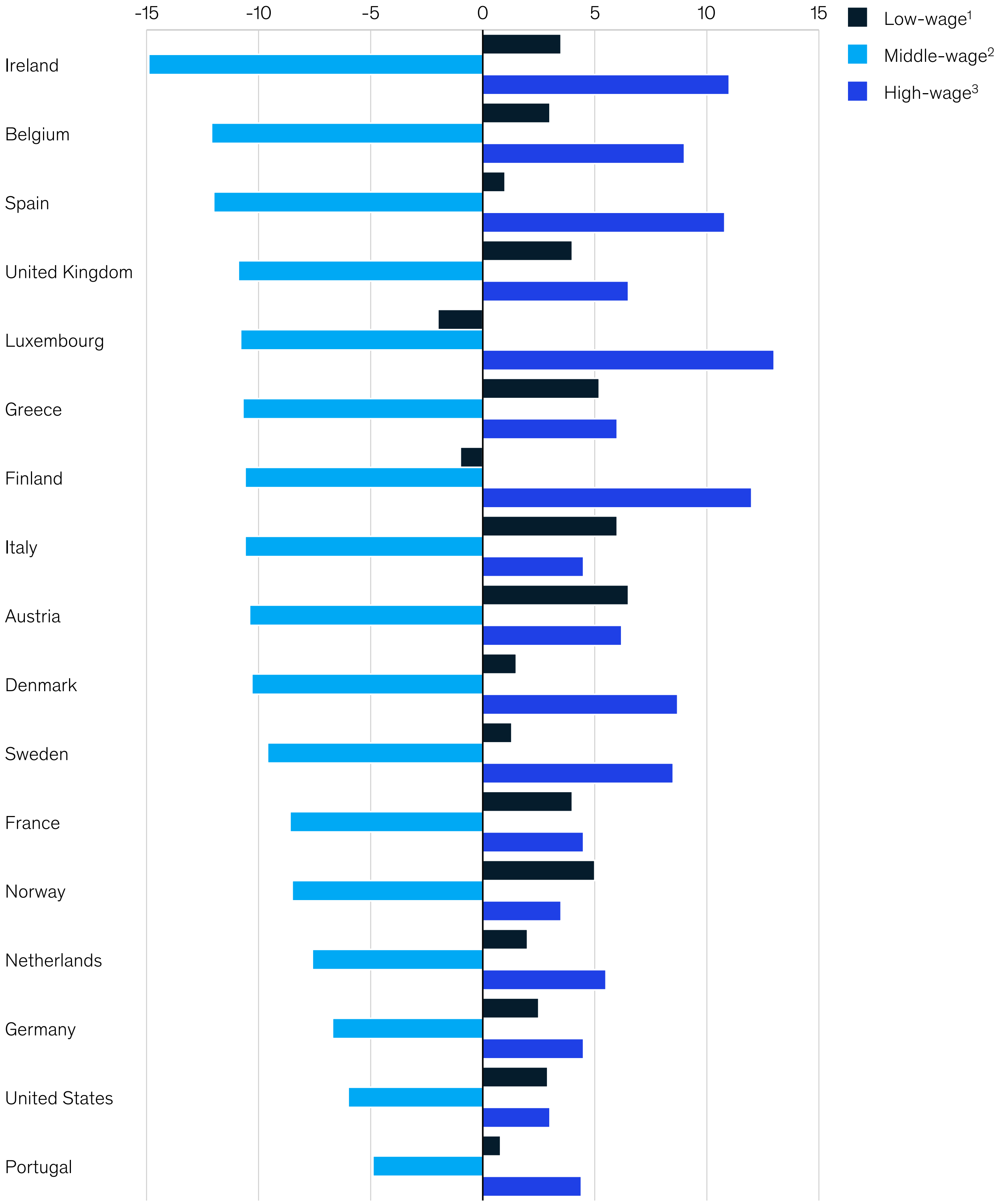
[1] Excludes the outlier year of 1921 (productivity growth of 6%, change in employment rate of -9%) to make graph more readable.
[2] Excludes real estate sector.

Source: Bank of England; ONS; McKinsey Global Institute analysis

Exhibit 5

Since the early 1990s, the share of middle-wage occupations has declined as income polarization has increased.

Change in occupational employment shares in low-, middle-, and high-wage occupations in 16 EU countries and the US, 1993–2010, %



1 Laborers and service workers; lower-wage jobs barely allow workers to provide for day-to-day needs and do not allow saving for retirement.
2 Clerks, operators, and assemblers.
3 Professionals and managers.

Source: Maarten Goos, Alan Manning, and Anna Salomons, "Explaining job polarization: Routine-biased technological change and offshoring," *American Economic Review*, Volume 104, Number 8, August 2014; McKinsey Global Institute analysis

Technology diffusion can also exacerbate inequality, as highlighted in the seminal work of Nelson and Phelps.[28] While rising inequality is not necessarily permanent, prospects for reducing it will depend on the mechanisms of diffusion, the shift in demand for workers' skills and their ability to acquire new ones, and whether technology shifts still enable all workers to obtain employment at the same real wage.[29]

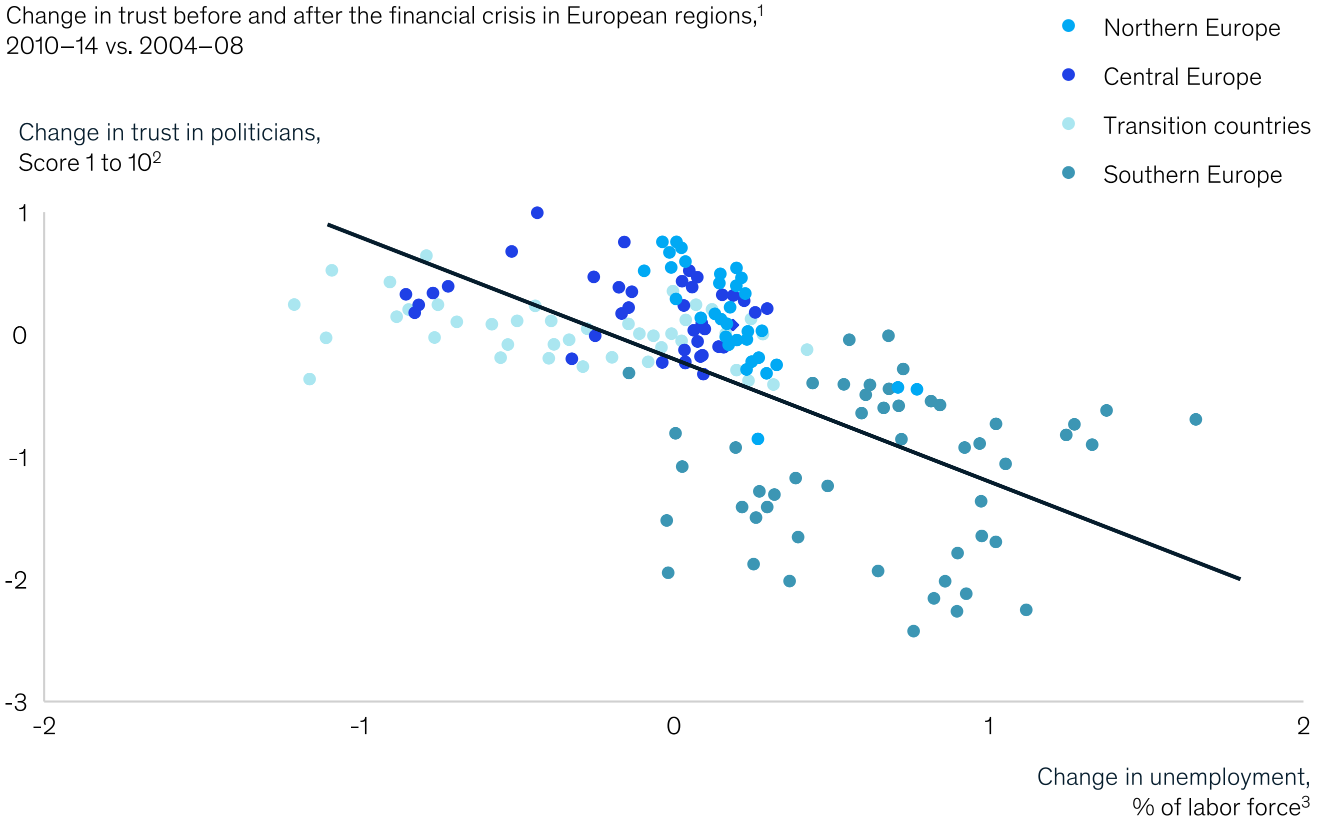
Polls show trust in government in some advanced economies has declined.[30] Increasing unemployment rates are one factor (Exhibit 6). Recent research shows that inequality's effect on political and social stability could be due less to its absolute level and more to rapid changes, which can alter long-held views about what constitutes a just, fair, and attractive society. Under a "stable equilibrium," the prevailing level of inequality will likely not influence people's sense of well-being as much, according to this research. However, if the stable equilibrium is disrupted and society moves into an "inequality disequilibrium"—in which a person's judgment about

[28] Richard R. Nelson and Edmund S. Phelps, "Investment in humans, technological diffusion, and economic growth," *American Economic Review*, Volume 56, Number 1, March 1966. See also Philippe Aghion, Peter Howitt, and Gianluca Violante, *Wage inequality and technological change: A Nelson-Phelps approach*, 2003.
[29] Joshua D. Hall, *The diffusion of technology, education and income inequality: Evidence from developed and developing countries*, November 5, 2009.
[30] See *Trust in government*, OECD, Directorate for Public Governance.

Exhibit 6

Increases in the level of unemployment are associated with deterioration in trust in politicians.

Change in trust before and after the financial crisis in European regions,[1] 2010–14 vs. 2004–08



[1] Data cover 215 NUTS2 regions in Denmark, Finland, Iceland, Ireland, Sweden, the United Kingdom (Northern Europe); Cyprus, Greece, Italy, Portugal, Spain (Southern Europe); Austria, Belgium, France, Germany, Netherlands, Switzerland (Central Europe); Bulgaria, Czech Republic, Estonia, Hungary, Poland, Romania, Slovakia, and Slovenia (Transition countries).
[2] Trust is defined by an independent variable measured by the European Social Survey, which scores trust on a 0–10 scale based on the following question: "… please tell me on a score of 0–10 how much you personally trust each of the institutions I read out. 0 means you do not trust an institution at all, and 10 means you have complete trust. Firstly… [institution tested for]".
[3] Unemployment rate is measured by Eurostat, and measures the number of people unemployed as a percentage of the labor force.

Source: Yann Algan et al., *The European trust crisis and the rise of populism*, CEPR Discussion Papers, 2017; European Social Survey; Eurostat; McKinsey Global Institute analysis acceptable norms for society is ruptured—this together with uncertainty about the future can negatively affect societal well-being.[31]

One straightforward, albeit subjective, definition of this perception of disruption can be found in *Hillbilly Elegy*, the memoir of J. D. Vance, a Yale graduate who grew up in a deindustrialized Rust Belt town. Vance describes economic insecurity within his community, alongside a culture of moral and social decay. "If you believe that hard work pays off, then you work hard," the author writes. "If you think it's hard to get ahead even when you try, then why try at all?"[32] If "middle class" is typified by an aspiration to advancing in life through education and hard work, then we need to understand why that narrative is broken, since it underlies our societies.

[31] Gøsta Esping-Andersen and Lesia Nedoluzhko, "Inequality equilibria and individual well-being," *Social Science Research*, February 2017, Volume 62; Jonathan Kelley and M.D.R. Evans, "Societal inequality and individual subjective well-being: Results from 68 societies and over 200,000 individuals, 1981–2000," *Social Science Research*, February 2017, Volume 62.

[32] J. D. Vance, *Hillbilly Elegy: A Memoir of a Family and Culture in Crisis*, New York, NY: HarperCollins, 2016.

2. GDP, well-being, and welfare: How we measure the impact of technology

Comparisons of living standards over time and across countries have often relied on measuring GDP per capita, adjusted for purchasing power. In this paper, we look more broadly at the potential impact of technology diffusion, and the associated choices by governments and businesses, on societal well-being. No single methodology for quantifying these effects has been established, so we draw inspiration from four complementary (and somewhat overlapping) branches of thinking: alternative indicators of economic and social progress, research on happiness and subjective well-being, health economics, and welfare economics. Each of these approaches lends itself to a different type of analysis, as explained below. All highlight an important truth: in a complex economy, life satisfaction is determined by multiple positive and negative components, which in turn affect different individuals differently. We therefore need methods that go beyond simple aggregates.

For this paper, we synthesize the broad spectrum of factors that individuals and societies value into a societal well-being framework. We then explore six of these factors more fully in the thematic deep dives that follow, on job security, material living standards, health and longevity, education, environmental sustainability, and equal opportunities. Finally, for our impact quantification, we narrow down the set of factors further, to focus on those that are possible to incorporate robustly into a calculation of GDP-equivalent welfare.

Our framework: Key factors of societal well-being

A significant body of research exists to provide measures of well-being that go beyond GDP. The Stiglitz Commission report was one of the first to propose alternative indicators of economic performance and social progress.[33] Other sets of indicators have been proposed through the United Nations' Sustainable Development Goals, with some trials of summary measures such as the UN's Human Development Index and the Social Progress Index put forward by Harvard economist Michael Porter and his colleagues.[34] The OECD's Better Life Index captures a comprehensive set of dimensions that have value to individuals and society, and many countries, such as New Zealand, have launched their own well-being initiatives, with associated metrics.[35]

These frameworks converge, as they all attempt to address some of the key shortcomings of GDP as a measure of progress. Some of them, including the World Happiness Index and Richard Layard's work on happiness, also build on large-scale analysis of self-reported life satisfaction and other data, allowing researchers to distill the factors that are most consequential for people's well-being.[36] Such research often finds that household income is only one of many factors, with social life, relationships and health, and not being unemployed also being important contributors to well-being (Exhibit 7).

[33] Joseph E. Stiglitz, Amartya Sen, and Jean-Paul Fitoussi, *Report by the Commission on the Measurement of Economic Performance and Social Progress*, 2009.
[34] See for example, Michael E. Porter and Scott Stern, *Social Progress Index*, Social Progress Imperative, 2017.
[35] *Policy use of well-being metrics: Describing countries' experiences*, OECD, November 2018.
[36] John F. Helliwell, Richard Layard, and Jeffrey D. Sachs, *World Happiness Report 2019*, March 2019; Richard Layard, *Happiness: Lessons from a New Science*, New York, NY: The Penguin Press, 2005.

For this paper, we have summarized the factors into the ten shown in Exhibit 8. We believe this framework to be comprehensive and fit for the purpose of analyzing technology impacts but acknowledge that it is only one way of presenting the different dimensions of well-being.

We start with basic economic prosperity, most viscerally felt by individuals through job security and material living standards, especially in terms of the purchasing power of their wages. We include education in this group, given its significant influence on people's prosperity over their lifetimes.[37]

The second group of factors considers aspects of life that are known to contribute to individual well-being, over and above economic prosperity. These include health—one of the largest factors in well-being—safety, housing, and social connectedness. The last refers to the crucial role that relationships play in determining people's happiness, either online or offline, whether at home, at work, or in the community.[38] Social connectedness is also correlated with health; for example, a growing literature looks at the consequences of loneliness on mental health.[39]

The third and fourth groups operate less at the individual and more at the societal level. Sustainability—both economic and environmental—is an important consideration, so that humans' instinctive tendencies to prioritize short-term gains and to discount future risks do not cause long-term harm. Finally, the fabric of society is fundamentally dependent on perceptions of fairness, reflected in the degree to which all members benefit from their rights

37 Technically, education is mostly a driver of the other factors rather than an independent driver of well-being, but given its prominence in human capital and economic development discussions, we have included it separately. See, for example, *Education for global development*, "Why education matters for economic development," blog entry by Harry A. Patrinos, May 17, 2016, blogs.worldbank.org/education/why-education-matters-economic-development.

38 Social media is a significant recent form of connectedness that can have welfare consequences. See Paul Best, Roger Manktelow, and Brian Taylor, "Online communication, social media and adolescent well-being: A systematic narrative review," *Children and Youth Services Review*, June 2014, Volume 41.

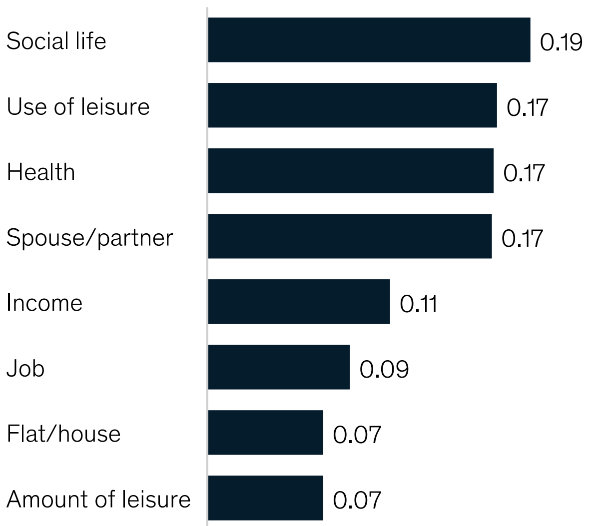
39 Ed Diener et al., "Social well-being: Research and policy recommendations," in John F. Helliwell, Richard Layard, and Jeffrey D. Sachs, eds., *Global Happiness Policy Report: 2018*, Global Happiness Council, 2018.

Exhibit 7

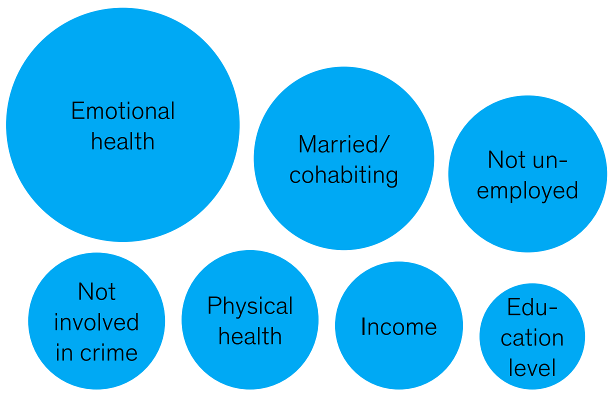
Many factors besides income contribute to individuals' well-being.

Factors affecting individual well-being in the United Kingdom

Increase in self-reported life satisfaction, on a scale from 0 to 10 for a unit increase in each factor



Determinants of life satisfaction at age 34, Bubble size = partial correlation coefficient



Source: British Household Panel Survey, 1996–2009; British Cohort Study; *Measuring wellbeing and cost-effectiveness analysis: Using subjective wellbeing*, What Works Centre for Wellbeing, Discussion paper 1, December 2016; McKinsey Global Institute analysis and have equal access to opportunities. Overall, societal trust—important for both material and nonmaterial well-being—is shaped by all of these factors over time.[40]

It is tempting to try to assign weights to these factors, and many of them can indeed be measured or proxied using quantitative metrics. However, our literature survey overwhelmingly shows that, first, they are all important; second, they are all highly interconnected; and third, they are affected through many direct and indirect channels.

[40] Social trust is often found to be lower where income inequality is greater. John F. Helliwell, Haifang Huang, and Shun Wang, "Changing world happiness," in *World Happiness Report 2019*.

Exhibit 8

Key contributors to societal well-being can be summarized in a framework of ten factors and mapped to our welfare calculation.

Well-being factors		Sub-factors	Covered in thematic deep dives	Explicitly included in welfare model	Components of welfare modeling impacted
Prosperity	Job security	Risk of unemployment, job stability, job quality	●	●	GDP, consumption to income ratio, consumption inequality, risk aversion to unemployment, health and longevity[1], leisure[2]
	Material living standards	Wages, purchasing power, leisure, inequality, wealth	●	●	GDP, consumption to income ratio, consumption inequality, leisure
	Education	Quantity, quality, and accessibility of education	●		(GDP[3])
Individual well-being	Health	Life expectancy, physical and mental health	●	●	Health and longevity
	Safety and housing	Personal, material and cyber-security, quality and affordability of housing			(GDP[3])
	Social connectedness	Quality and number of relationships, community, social capital			Not explicitly modeled
Sustainability	Environmental sustainability	Climate change, pollution, waste, biodiversity, natural capital	●		(GDP[3])
	Economic sustainability	Long-term tangible, human, and knowledge/ intellectual capital			(GDP[3])
Fairness and trust	Equal opportunities	Social mobility, inclusive-ness, equal access to services	●		(GDP[3])
	Trust in society	Trust in actors in society, privacy, institutional capital			Not explicitly modeled

[1] Through stress component of health and longevity.
[2] Through forced component of leisure.
[3] Incremental impact of technology scenarios captured implicitly through the impact of productivity improvements due to technology diffusion, automation, and innovation.

Source: United Nations' Sustainable Development Goals; OECD's Better Life Index; Human Development Index; New Zealand Living Standards Framework; Joseph E. Stiglitz, Amartya Sen, and Jean-Paul Fitoussi, *Report by the Commission on the Measurement of Economic Performance and Social Progress*, 2009; Michael E. Porter and Scott Stern, Social progress index, Social Progress Imperative, 2017; Ed Diener et al., "Social well-being: Research and policy recommendations," in John F. Helliwell, Richard Layard, and Jeffrey D. Sachs (eds.), *Global Happiness Policy Report: 2018*, Global Council for Happiness and Well-being, 2018; Kirk Hamilton and Cameron Hepburn, *National Wealth: What is Missing, Why it Matters*, Oxford Scholarship Online, October 2017; McKinsey Global Institute analysis.

For example, job security can create financial prosperity, reduce stress, enhance social relationships, and boost health and well-being. More leisure time enables more time to be spent with friends and family, enhancing social connectedness. Trust in society is often negatively linked to poor job security and levels of safety.[41] We have not attempted to create a quantitative index or other summary metric; rather, for quantification, we have focused on welfare, which captures many, but not all, components of this framework.

A focus on six themes relevant for "Tech for Good"

We have chosen to go deeper into six well-being themes that are most frequently discussed as particularly relevant in the context of technology adoption. These themes—job security, material living standards, health, education, environmental sustainability, and equal opportunities—are areas in which technology could potentially be disruptive and create problems but can also be used to mitigate those same risks and add significantly to welfare. They are also areas where existing use cases illustrate the potential of technology to "do good." Other MGI and McKinsey research covers some of the other factors, such as housing, safety, and security.[42]

We start by taking a new perspective on the future of work. Surveys of people's attitudes indicate anxiety about technology and jobs.[43] As we have found in previous MGI research, job security and wages could be disrupted by rapid technology adoption. In our deep dive, we consider ways in which technology itself could alleviate these issues. Technology may also exacerbate inequalities. We therefore look at two key enablers of equality of outcomes: education and equal opportunities. Health, including longevity, is included as a theme due to its dominant role in people's well-being: it is often cited as one of the most important factors in its own right. Critically, being healthy also contributes to job security, wages, and social connectedness. Finally, we consider the theme of environmental sustainability. Technology holds significant promise to reduce the costs and improve the effectiveness of actions to preserve and enhance the planet's natural capital.

Economic welfare as a quantification of technology's impact

We use the concept of economic welfare as a way to put the well-being factors on a par with GDP and to simulate the impact of technology paths on them quantitatively. Welfare is a specific branch of economics that quantifies utility across the population and allows us to present well-being outcomes in monetary—or "consumption equivalent"—terms. For this paper, we draw extensively on a welfare methodology proposed by Charles I. Jones and Peter E. Klenow of Stanford University, and subsequently built on by various researchers, including those at the International Monetary Fund.[44]

[41] Carol Black, among others, has focused on the health aspects. See, for example, *Working for a healthier tomorrow: Work and health in the UK*, UK Government Department of Work and Pensions, March 2008. For social relationships, see *World Development Report, Jobs*, World Bank, 2013. For trust, see Yann Algan et al., *The European trust crisis and the rise of populism*, Brookings Institution, September 2017. For our prior research on job security, see *Testing the resilience of Europe's inclusive growth model*, McKinsey Global Institute, November 2018.

[42] See, for example, *Reinventing construction: A route to higher productivity*, McKinsey Global Institute, February 2017; *Policing: A vision for 2025*, McKinsey & Company, January 2017; *Laying the foundation for success in the connected-building era*, McKinsey & Company, October 2018; *Six ways CEOs can promote cybersecurity in the IoT age*, McKinsey & Company, August 2017.

[43] See, for example, Aaron Smith and Monica Anderson, *Americans' attitudes toward a future in which robots and computers can do many human jobs*, Pew Research Center, October 4, 2017; *Workplace stress continues to mount*, Korn Ferry, November 14, 2018.

[44] Charles I. Jones and Peter E. Klenow, "Beyond GDP? Welfare across countries and time," *American Economic Review*, September 2016, Volume 106, Number 9; Geoffrey J. Bannister and Alexandros Mourmouras, *Welfare vs. income convergence and environmental externalities*, International Monetary Fund working paper number 17/271, November 2017; Marc Fleurbaey and Guillaume Gaulier, "International comparisons of living standards by equivalent incomes," *The Scandinavian Journal of Economics*, September 2009, Volume 111, Number 3.

We take GDP as the starting point for quantifying economic welfare and then adjust it for key components that affect individuals' utility. The components of welfare that we include are:

— **GDP:** This represents the total income generated from production, accruing to labor and capital. For the purposes of this paper, GDP is synonymous with total income. The key factors in our well-being framework that are linked directly to GDP are job security (risk of and actual unemployment) and material living standards (which are largely determined by real wages). To the degree that goods such as education, health, housing, safety, and environmental protection are enhanced by automation and innovation inside the production boundary, such changes are implicitly captured in GDP. Similarly, the economic sustainability factor is reflected in GDP to the end of our modeling period (2030).

— **Consumption:** Only the proportion of income that is actually consumed—not saved—contributes to utility in each year. In line with welfare literature, we adjust utility for changes in the ratio of consumption to GDP. In our simulation, this is primarily driven by any changes to unemployment, which links back to job security in our well-being framework.

— **Consumption inequality:** This component captures the aversion of society to inequality. In line with the Arrow-Pratt approach to risk, we quantify it by estimating the variance of the distribution curve for consumption (where consumption is expressed in logarithmic terms). The variance is primarily influenced in our model by unemployment and wage inequality, both of which are driven by the occupational, sector, and skill shifts created by technology diffusion. We also include the impact of the changing income shares of labor and capital on consumption inequality.

— **Risk of unemployment:** Even if a person is employed, the risk that they might lose their job and the anticipated consequences in terms of earning loss are a factor in their well-being. Reports on the increasing precariousness of jobs, some of which can be linked to the gig economy, highlight this as a significant issue. We incorporate this risk aversion as a separate component in the welfare calculation, using the Arrow-Pratt variance method.[45]

— **Leisure:** Conceptually, people have a choice between work, which provides consumption-enabling income, and leisure. We model the likely increases in both the quality and quantity of leisure time due to automation and other productivity-enhancing technology. We adjust the leisure component to take into account unemployment: utility from hours of "forced leisure" due to unemployment is significantly lower than that of "voluntary leisure." In our societal well-being framework, job security and material living standards therefore have direct links to the value and quantity of leisure.

— **Health and longevity:** The longer people live, the more years they can enjoy the utility derived from the components above. We therefore model the likely improvements in life expectancy due to technology and incorporate this into the welfare calculation. However, it is clear that a healthy life year is significantly more valuable to individuals than simply an extra year of life. We therefore add a separate health component.

Most of these components of welfare map directly to aspects of our well-being framework. However, there are factors in the framework that are not included as separate components in the welfare calculation, for several reasons. First, some of them, such as education and equal opportunities, are drivers of welfare rather than outcomes. We include this effect in our estimates for income, consumption, and inequality. While some would argue that they have an intrinsic value over and above the other components, we have considered quantification of this to be outside the scope of the modeling for now (see Box 3, "Limitations of our modeling approach").

[45] Alexander Hijzen and Balint Menyhert, *Measuring labor market security and assessing its implications for individual well-being*, OECD Social, Employment and Migration Working Papers number 175, January 2016.

Safety, housing, social connectedness, and trust are all important contributors to well-being, but difficult to model. There is limited comprehensive evidence on how different technology adoption paths might affect them and little research we can draw on to establish a quantitative methodology for estimating the effects in consumption-equivalent terms. Economic sustainability is implicitly already included in our estimates of future GDP (to the end of our modeling period, 2030). Environmental sustainability is clearly an area of significant research. While we include it in the thematic deep dives, it is outside the scope of our welfare calculation.

Box 3

Limitations of our modeling approach

The modeling approach adopted for this paper has a number of limitations, as well as features that are important to understand explicitly to avoid overstating the significance of the findings. Three particular areas invite caution when interpreting the results: scope, scenarios, and assumptions.

As described above, our welfare quantification excludes a number of components that are nevertheless important for well-being, such as social connectedness and environmental sustainability. The scope of technologies we have considered is also limited: when talking about technology adoption, we refer to automation, AI, ledger technologies, and all previous digital technologies such as big data, the cloud, mobile internet, and IoT. However, in the modeling we do not include other sets of technologies such as augmented or virtual reality, or technologies at the intersection of biology and engineering. The dimensions of welfare loss that we measure, such as risk of unemployment or income inequality, are based on a commonly used variance approach, but this computation of risk may be overly restrictive.[1] The time frame chosen to 2030 is helpful for illustrating transition effects but should not be considered an end-point in a technology wave that is likely to last decades.

The scenarios we model are intended as "what if" simulations. In other words, we try to understand what would happen to GDP and other welfare components if, for example, businesses focused their technology adoption more on innovation rather than pure cost reduction, or what would be the consequences of government support for R&D in creating and adopting health technology. We do not claim to know precisely how these scenarios would come about. More importantly, we have considered only a very limited set of choices at governments' and businesses' disposal, as our focus is primarily on market dynamics rather than nonmarket interventions. For businesses, we assume economic rationality; for example, we model actions on R&D investment and retraining up to the point where their return matches the cost of capital. For government, we posit a narrow range of choices where we believe the benefits would exceed the direct costs. These "self-financing" policies are intended to illustrate the impact they could have on technology adoption paths. This approach explicitly excludes many relevant, and possibly bolder, policy levers, such as major education reform, taxation, benefit systems, and minimum wages.

Finally, the assumptions that feed the model are based on previous modeling work by MGI, external data sources, and a literature review. A wide range of estimates is available for most parameters. We use our judgment to choose the ones that are more recent or more robust and best triangulate with other estimates. We have conducted sensitivity analysis to identify inputs that could be particularly consequential and tested our assumptions with external experts. For more detail on scope, scenarios, modeling methodology, assumptions, and data sources used, see the technical appendix.

1 See, for example, Juan Carlos Cordoba and Maria Ripoll, *Beyond expected utility in the economics of health and longevity*, Iowa State University, Department of Economics working paper number 13008, March 2013.

3. Using technologies to address structural and transition challenges

AI and other frontier technologies, which rely on a foundation of previously rolled-out digital technologies including big data and the cloud, hold the promise of significant benefits to society, but also heightened risks and challenges to individuals and institutions from the structural changes and transitions they will bring about. These could include greater income inequality, an increased risk of unemployment, and higher stress levels, among others.[46] To what extent could technology itself help overcome or mitigate these challenges?

In this chapter, we look in detail at six non-exhaustive, broad themes that are frequently raised in discussions and for which technological applications themselves could help mitigate negative outcomes and improve well-being. The six themes—job security, material living standards, health, education, equal opportunities, and environmental sustainability—are undergoing some of the fastest changes and are also areas in which technology can deliver some of the biggest impact, both positive and negative.[47] Moreover, to a greater or lesser degree, they are all components that can be incorporated into the calculation of welfare. This analysis therefore also serves as a bottom-up view that helps calibrate the estimates in chapter 4 of this paper.

Our examination is based on a library of about 600 use cases that we assembled using a wide range of industry sources, including insights from previous McKinsey Global Institute work, experts, and academic literature (see Box 4, "Our library of use cases"). These cases are illustrative of ways in which technology can make a difference but are, obviously, not exhaustive. They often highlight both sides of the story. For example, while technology can increase the cost of healthcare, in the form of expensive new treatments such as cell therapy, it could also be a powerful tool to improve efficiency in the system, by identifying areas of waste.[48] Likewise, in the workplace, while automation could displace many jobs, digital platforms are increasingly being used to equip workers with new skills and match employers and job seekers more efficiently than is possible through traditional labor market mechanisms.

We are not seeking to sugar-coat the disruptive effects of automation and other technologies, which are especially relevant in the themes of job security and material living standards. The loss of income accompanying job displacement would have a severely negative and immediate effect on well-being that job platforms or other technologies could not offset, at least not rapidly. Nonetheless, technology does provide a tool kit of solutions to ongoing and significant problems in our societies. We call this tool kit "Tech for Good." By deploying it, business and government can help ease the social and workforce transitions that acceleration of technology innovation itself creates.

[46] Christoph Weinert et al., "How do users respond to technostress? An empirical analysis of proactive and reactive coping," *Proceedings of the 52nd Hawaii International Conference on System Sciences*, 2019.
[47] With the exception of health, these areas correspond to ongoing work streams for the "Tech4Good" summit series initiated for the French presidency in 2018. See *Digital stakeholders make concrete commitments for the common good*, gouvernement.fr, May 24, 2018.
[48] See, for example, Florian Leibert, "4 ways to help AI improve healthcare and cut costs," *ITU News*, August 21, 2018.

Box 4

Our library of use cases

Our library about use cases focuses on a range of technological applications and how they could be used in several thematic areas. We based our selection of the technologies on existing MGI frameworks, building on MGI's 2013 report on disruptive technologies.[1]

We conducted a literature review to identify the impacts of these technologies on all the components of our well-being framework. To do this, we drew from a range of sources. We leveraged the use-case libraries we had already built for AI and other specific technologies and areas of application, and other examples from colleagues in McKinsey practices.[2] We also leveraged a number of analyses from institutions such as the Organisation for Economic Co-operation and Development, the International Telecommunication Union, and the Ellen MacArthur Foundation, which cover all or part of our framework.[3] We complemented our findings with a press search to ensure that our library was up to date with innovations that had already shown some level of maturity and potential for scalability.

Using this library, we determined the extent to which each well-being factor in our framework could be affected by a certain use case, either positively or negatively, or not at all. We normalized the scale of impact from "moderate" to "significant" and "strong." Each use case was mapped to all the well-being factors it impacts; for example, deploying renewable energy technologies directly affects environmental sustainability, but also health, by reducing air pollution. Similarly, as many applications make use of several technologies, this methodology provides a sense of the frequency with which different technologies contribute to different well-being themes. We captured only first-order effects of the use cases. For example, use cases that have a positive net present value improve overall economic sustainability; however, we focused our mapping on the direct effects.

For some use cases that did not fit directly into our positive-to-negative scale, we assigned a qualitative rating. For some use cases whose description already included quantifications of their potential economic benefits, we took these quantifications into account when they appeared reliable and could be used to compare their relative importance. An example is health, where we used the magnitude of impact based on existing literature as the element of comparison in our weighting. Some use cases already had proven impact: for example, technologies that monitor patients' health remotely on a continuous basis and transmit the data for analysis and intervention to healthcare providers have been shown to reduce mortality rates by about 20 percent.[4]

Where such quantifications were not available, we drew from our literature review and expert interviews for more qualitative assessments of the relative importance of the issues addressed, which we normalized using the same scale.

We realize the limitations of this approach, which is only one way of summarizing the impact of technology applications on well-being factors. While this approach does not allow us to reliably rank the expected impacts of technologies on society, we use it as an indication of the current level of maturity, and breadth of impact, of these technologies.

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1 *Disruptive technologies: Advances that will transform life, business, and the global economy*, McKinsey Global Institute, May 2013. Some of these technologies have evolved substantially since that publication. For example, cloud technology was a pioneer technology at the time of that report but has since become an industry standard and the foundation for broader technological shifts including platform-based innovation and data analytics. Other technologies such as blockchain were not part of the 2013 list.

2 For example, *Notes from the AI frontier: Insights from hundreds of use cases*, McKinsey Global Institute, April 2018; *Notes from the AI frontier: Applying AI for social good*, McKinsey Global Institute, December 2018; *Smart cities: Digital solutions for a more livable future*, McKinsey Global Institute, June 2018. We also drew on use cases and experience from McKinsey's Noble Intelligence initiative, which uses AI and other advanced analytics techniques to help advance causes for societal good in areas such as global public health, improving labor, and helping vulnerable populations.

3 See in particular the OECD's Well-Being Research and Going Digital initiatives (oecd.org/statistics/measuring-well-being-and-progress.htm; oecd.org/going-digital/); the ITU's AI for Good global summit (aiforgood.itu.int/); and the Ellen MacArthur Foundation's publications on the circular economy, in particular *Artificial intelligence and the circular economy: AI as a tool to accelerate the transition* (2019) and *Growth within: A circular economy vision for a competitive Europe* (2015).

4 Thomas London and Penelope Dash, *Health systems improving and sustaining quality through digital transformation*, McKinsey & Company, August 2016.

Some categories of technology that have the potential to do good

To ground our research, we selected a subset of technologies that have been or are in the process of scaling up adoption. AI and digital technologies are a main focus of this list. At the highest level, the technology categories are:

— Data and AI, which include both advanced analytics and artificial intelligence

— Connectivity and platforms, under which we group digital platforms, the mobile internet, and the cloud

— Robotics, under which we include both advanced robotics increasingly able to augment humans in the workplace and traditional robotics, in which machines reproduce repetitive human actions, as well as autonomous and near-autonomous vehicles

— The Internet of Things, which uses networks of sensors and devices to collect data and optimize processes

— Virtual and augmented reality, an artificial environment created with software and hardware that, in the case of augmented reality, provides the ability to overlay digital information into real-world settings

— Digital fabrication including 3-D printing

— New materials and biotech, which include advanced materials, such as new lightweight materials, and next-generation genomics

— Clean tech, which primarily consists of renewable energy sources such as sun and wind energy, supported by devices for energy storage

As noted, some of these technologies could prove highly disruptive in some themes, especially but not limited to job security and material living standards. Nonetheless, focusing on use cases with positive impact in our six themes illustrates the significant potential for these technologies to mitigate transition risks. It also highlights some clear technology patterns (Exhibit 9).

The first pattern is that proven uses of technology to improve outcomes can be found across all of the themes. All of the technology categories can contribute, but in some cases, the effect is more concentrated on the use cases of one theme: for example, augmented reality's applications are largely to be found in education, while clean tech is obviously pertinent to environmental sustainability.

The second pattern is that three of the technology categories have a very broad, general applicability across multiple themes and underlie most of the others. The first two categories—data and AI, and connectivity and platforms—are the most widely applicable across all six areas and, within them, platforms and mobile internet are especially relevant to equal opportunities and education. A third category, robotics, also has applications across all six areas, especially for inclusiveness and environmental sustainability.

Advanced analytics and AI are particularly prevalent: they feature in more than 60 percent of our use cases. They are essential Tech for Good tools in that many of their applications have the potential to mitigate or alleviate technology-related transitions and to improve well-being, thereby lifting welfare. Among other characteristics, they can ensure that help is targeted at the right people most effectively. AI capabilities including natural language processing can be used to tailor classes to individual students, for example, adjusting for their level of understanding and measuring their progress, and thereby improving the efficiency of learning tools that are a key for individual well-being.[49] They also have applications that serve the common good of society more broadly. For example, the use of analytics to detect leaky water pipes and optimize pump pressure can not only bring cost savings on the order of 15–25 percent for municipal authorities, according to our estimates, but also save a precious resource that is scarce in many countries.[50]

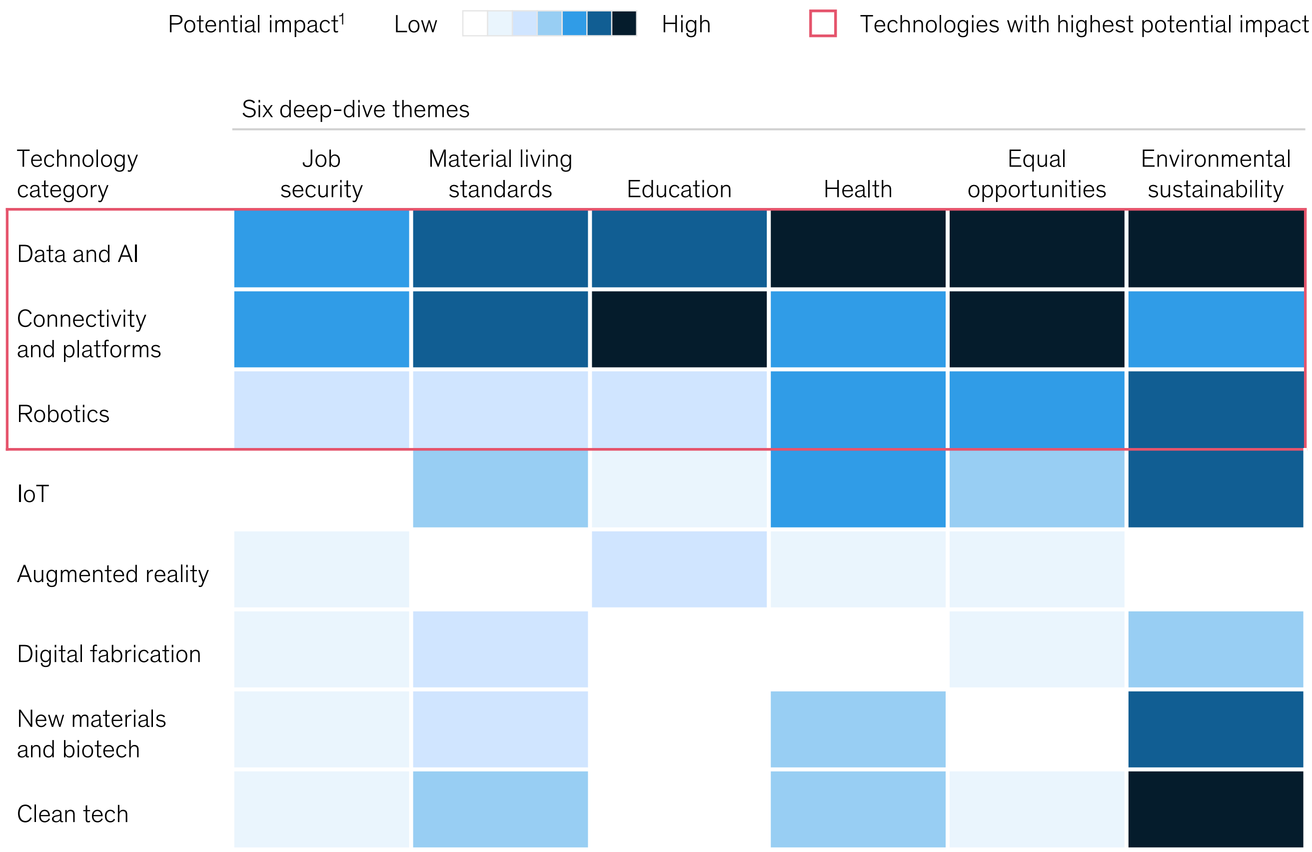
Connectivity and platforms, which include the mobile internet, are also key to supporting well-being. Almost by definition, little can be done with technology without the requisite software and user interfaces and the internet; they are core to Tech for Good applications in 35 percent of the use cases we compiled, with impact covering all aspects of well-being. Platforms are already widely used to improve the matching of employers and workers, create new forms of independent work, and raise skill levels—thereby addressing critical issues of job security and material living standards. They also have wide-ranging and broader social applications. These include cybersecurity, where distributed collaboration platforms allow volunteers (white-hat hackers) to test software and algorithms to detect vulnerabilities; environmental sustainability, for which waste-tracking platforms allow citizens to report illegal waste dumping directly to authorities; and economic sustainability, for which crowdsourcing platforms provide a route for grass roots innovation.

[49] *Notes from the AI frontier: Applying AI for social good*, McKinsey Global Institute, October 2018.
[50] *Smart cities: Digital solutions for a more livable future*, McKinsey Global Institute, June 2018.

Exhibit 9

Three technology categories have significant potential to improve key areas of well-being.

Based on positive use cases of technology,
Total number of use cases = about 600



[1] Potential impact assessed as relative number and impact of use cases; use cases involving several technology categories counted in each relevant category.
Source: McKinsey Global Institute Technology for Good use-case library; McKinsey Global Institute analysis

The mobile internet, for its part, is a powerful channel to reach individuals and enable both better access and more equal opportunities. Mobile connectivity and platforms can be used in digital finance and telemedicine, for example, giving millions of people the opportunity to access services from which they have been excluded, at times because of where they lived. In India, for example, based on the success of field trials, we estimate that telemedicine could replace as many as half of in-person outpatient consultations by 2025, saving $4 billion to $5 billion annually while also enabling people in rural areas to reduce their dependency on unqualified medical practitioners.[51]

Robotics, which has applications in 16 percent of our use cases, emerges as an especially significant enabler of equal opportunity and environmental sustainability. Advanced robotics, such as exoskeletons and chairs with tablet and voice control, can help people with specific disabilities to communicate with others and increase mobility. Several companies have already obtained approval from the US Food and Drug Administration to commercialize exoskeleton devices. Autonomous and semiautonomous vehicles can also increase mobility for people with disabilities and, according to one estimate, could enable new employment opportunities for approximately two million individuals with disabilities, saving $19 billion annually in healthcare expenditures in the United States.[52]

Our use case list only scratches the surface in some areas of need. For example, we may underestimate the potential gains in the field of healthcare. This is due in part to the sheer number of existing and potential threats to health that will remain prevalent in the coming decade and require new research and technological answers, and in part to the fact that certain low-technology solutions such as better woodstoves and effective water filters are well known in the medical community but insufficiently deployed across the world.[53] For all their utility, the technologies have limitations and face obstacles, including cost and user and regulatory acceptance. Nonetheless, across the themes we examine, many applications have relevance to social challenges and would, if used widely, have considerable impact (Exhibit 10).

[51] *Digital India: Technology to transform a connected nation*, McKinsey Global Institute, March 2019.
[52] *Self-driving cars: The impact on people with disabilities*, Ruderman Foundation, 2019, rudermanfoundation.org/white_papers/self-driving-cars-the-impact-on-people-with-disabilities/.
[53] "Ten recent low-tech inventions that have changed the world," *MIT Technology Review*, February 27, 2019.

Exhibit 10

Positive use cases are already being realized across well-being factors and technology categories.

	Job security	Material living standards	Education	Health	Equal opportunities	Environmental sustainability
Data and AI	AI augmentation complements employee skills, eg, in front-line customer-service roles	AI chatbots help immigrants navigate the immigration process in the US AI can advise the vulnerable in financial decisions, eg, on pay-day loans	Intermediated revival education uses AI to build personalized journeys and improve learning outcomes Virtual facilitators help teachers to adapt curriculum to student needs	AI-driven drug discovery and tests can reduce time and cost by 4- to 5-fold AI-powered diagnosis tools improve accuracy, eg, risk of breast cancer in histopatho-logical images	Speech generating devices (SGD) help people with speech disorders AI can reduce discrimination in recruiting, by surfacing biases	AI and IoT power automated traffic optimization helping to reduce emissions AI-driven reverse logistics infrastructure improves product sorting and recycling
Connectivity and platforms	Career orientation and job matching systems can reduce job search times by 40–50% Digital cloud-based work-spaces complement geographic mobility	Digital portals simplify access to public services Food-donating applications help match food-insecure with donors	Digital support and nudging systems reduce administrative burden on teachers Tablet-based learning improves results and decreases distress for students with dyslexia	Maternal health applications and SMS platforms provide assistance to women in developing countries	Inclusive digital tech communi-ties can reduce "insider-outsider" dynamic Digital platforms for disabled travelers provide better access	Public waste-tracking platforms can detect illegal waste dumping in real-time Second-hand market places reduce waste by extending life-span of goods
Robotics	Robotics helps to shift human labor to high-value work, e.g. from data gathering to data interpretation	Autonomous drones can be used in agriculture to reduce costs of e.g. screening	Automated grading allows schools to replace standard tests with more complex tasks Automation of admin tasks frees up time and resources for educational professionals	Robotic surgical devices controlled by a human can enable surgeons to perform surgery remotely	Exoskeletons empower dis-abled people in their everyday life Semi-autonomous vehicles increase mobility of people with deafness and blindness	Robotic disassembly of electronic components supports end-of-life recycling of products Autonomous vehicles could help reduce carbon emissions and fuel consumption by up to 10–20%
IoT	IoT predictive maintenance improves local competitiveness Wearable devices can track health metrics for workers in hazardous environments	Near-field communication is used to prevent counterfeit drug trafficking, as demonstrated by Interpol	Responsive assistance provides wearable devices that provide real-time support to pupils Eye-tracking solutions can be used to adapt students' learning experiences	Smart pill bottles and ingestible sensors to monitor and promote adherence to doctors' orders IoT predictive maintenance can reduce health and safety risks in many working environments	Smart objects linked to geospatial information improve women's security, eg, invisible SOS buttons Augmentative and alternative communication tablets help para-lyzed patients	IoT monitoring in "smart grids" optimizes the production, distribution, and usage of electricity IoT detection of illegal logging prevents further deforestation

Source: McKinsey Global Institute analysis

Exhibit 10 (continued)

Positive use cases are already being realized across well-being factors and technology categories.

	Job security	Material living standards	Education	Health	Equal opportunities	Environmental sustainability
Augmented reality	AR in manufacturing can be used to train workers as an alternative to job automation	Augmented reality telesurgery improves access to quality surgeons in poorer and remote areas	AR/VR provides immersive experiences to close resource gaps in less well-served areas Digital graffiti help students transform neighborhoods into a living history book	AR/VR provides immersive experiences for medical training AR can create simulations of scenarios in which psychological difficulties occur, used for mental therapy	VR provides realistic experiences for people with physical disabilities Smart glasses can be used to help people with autism on cognitive, social, and emotional skills	AR may improve connectedness from remote places, reducing the need for commuting or business travel and contributing to the reduction of carbon emissions
Digital fabrication	3-D small-scale production creates new opportunities for small businesses	3-D printed construction materials can be used for affordable housing, e.g. social housing prototypes in France and the Netherlands	3-D printing can be used for prototyping in the education of design and architecture students	Bioprinting combines tissue culture and biomaterials to print human cells and tissues	3-D printing can be used to produce hyper-personalized products with specific features for people with disabilities	Just-in-time production using 3-D printing reduces waste by minimizing the quantity of material used
New materials and biotech	Innovations in 3-D printing materials reduce costs and make technology accessible for micro businesses	New materials improve yields in agriculture, eg, a non-toxic soil additive helps seeds thrive in dryer conditions	—	DNA sequencing helps to detect and prevent spread of certain diseases, eg, malaria	Bioprinting can be used to replace malfunctioning body parts for people with disabilities	Bioplastics and nanocellulose tested to replace traditional plastics in packaging
Clean tech	Renewable energy created more than 500,000 jobs globally in 2017	Renewable energy sources can create lower electricity costs in the longer-term, as storage capacity and efficiency improve	Electrification through renew-ables in rural areas supports education in poor countries Repurposed schoolbags with built-in solar chargers capture energy on the walk to and from school	Renewable energy can reduce local air pollution and reduce health risks with fossil fuel delivery systems	Smart power projects allow access to cook-ing appliances and small machinery for rural households	Renewable energy decreases reliance on finite resources

Source: McKinsey Global Institute analysis

Theme 1: Job security

Research shows that job security—which includes being unemployed or being worried about the risk of unemployment—has an asymmetric effect on well-being: whereas being employed is not associated with a strong effect on life satisfaction, losing a job or not being employed has a highly negative and lasting impact on life satisfaction, especially where it is linked to loss of income.[54]

As noted earlier, technological innovation in the past both created jobs, through innovation, higher wages, and higher demand, and destroyed them, through substitution by machines. While the long-term effects are positive, the short-term disruption from the transition can be wrenching.

From our use-case library, we see that sharing platforms and AI-driven decision-making can increase the speed and effectiveness of innovation within companies. The rapid creation of new and better products and services will not only benefit consumers, but also create more demand and offset some of the reduction in labor demand due to automation. These are critically important elements of job security, which is at the heart of well-being for many people. At the same time, we acknowledge that the effect of these and other technologies may take time to become tangible, whereas the impact of job losses could be felt more quickly.

Our work on AI and automation anticipates that some jobs will be displaced, others created including through a surge in innovation unleashed by the technologies, and almost all will change.[55] We have identified three key transitions relating to job security and the adoption of automation and AI that will need to be navigated.[56] First, millions of workers will likely need to change occupations: we estimate that about 75 million people worldwide will need to switch occupations by 2030 in the event that automation takes hold at a pace in the middle of our range of adoption scenarios. If the speed of adoption is faster, at the top end of our range, it could affect up to 375 million people, or about 14 percent of the global workforce.[57]

Second, workers will need different skills to thrive in the workplace of the future. Demand for social and emotional skills such as communication and empathy will grow almost as fast as demand for many advanced technological skills. Automation will also spur growth in the need for higher-level cognitive skills, particularly critical thinking, creativity, and complex information processing. Many companies already see skill gaps as a top priority, and almost two-thirds of firms we surveyed believe that at least 25 percent of their workforce will need to be retrained or replaced in the next five years.[58] Globally, some large companies including Walmart, SAP, AT&T, and emerging-market companies including Tata, Infosys, and Tech Mahindra are adopting broad “reskilling” initiatives, but they remain exceptions.[59]

Third, workplaces and workflows will change as more people work alongside machines. This will be challenging both to individual workers, who will need to be retrained, and to companies, which must become more adaptable. Such changes may not be easy to implement and may create significant friction in the economy. This mismatch risk is real, as automation will affect many sectors and geographies at the same time. Typically, a large

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54 See Alexander Hijzen and Balint Menyhert, *Measuring labor market security and assessing its implications for individual well-being*, OECD Social, Employment and Migration Working Papers number 175, January 2016; Sarah Fleche, Conal Smith, and Piritta Sorsa, *Exploring determinants of subjective well-being in OECD countries*, OECD Statistics working paper number 2012/01, 2012.
55 *Jobs lost, jobs gained: Workforce transitions in a time of automation*, McKinsey Global Institute, December 2017.
56 *Navigating a world of disruption*, McKinsey Global Institute, January 2019.
57 *Jobs lost, jobs gained: Workforce transitions in a time of automation*, McKinsey Global Institute, December 2017.
58 McKinsey & Company quarterly panel survey, November 2017.
59 See, for example, “Building the workforce of tomorrow, today,” *McKinsey Quarterly*, November 2018.

fringe of the population is not mobile in the short term, especially those who own their homes or have family commitments.

Even if unemployment does not materialize at a large scale, many workers' jobs will change. We have estimated that for about 60 percent of workers, around 30 percent of work activities have the potential to be automated, based on technologies that have already been demonstrated.[60] The prospect of even partial automation of their work can increase the fear of unemployment for many, including middle-class workers who have traditionally been more insulated from unemployment.

How can technology reduce the risk to job security? Critically, it will bring innovation that is valued by the economy and will thus boost demand for labor. As we will see in our modeling of potential welfare outcomes later in this paper, innovation is an essential element for achieving positive outcomes. To that end, collaboration platforms such as Slack and Asana, and communication solutions such as WebEx and Circuit, play an enabling role: they can be used to crowdsource ideas, help share knowledge across multiple locations, and create effective spaces for collaboration. Innovation can also be boosted by governments' adoption of platforms—following the lead of countries such as Estonia—making it easier to create and register a company. The World Bank estimates that the time it takes to start a business somewhere in the world has already fallen from about 50 days in 2005 to about 20 today on average.[61]

Alongside innovation, technology can make a significant contribution to workforce fluidity, helping people retrain and businesses redeploy human resources, while minimizing the time and cost of displacement. Digital platforms and AI can be used to improve the chances that job seekers find opportunities to match their skills and preferences. This can reduce the length of time people spend between jobs and improve their earnings prospects. For employers, talent-matching technologies can improve worker productivity and provide savings in recruiting, interviewing time, training, onboarding, and attrition costs.[62] Recent research further amplifies the significance of better talent matching for firm productivity and individuals' wage levels.[63] Learning platforms, remote learning technologies, and new forms of digital-based businesses can all start to bridge some of the remaining gaps. Such technology tools can enhance labor-market efficiency and on-the-job training, which international evidence suggests contribute to low unemployment (Exhibit 11).

Governments in some countries are launching initiatives to promote new skills. For example, Skills Norway, the country's agency for lifelong learning, offers individually adapted training online in literacy, numeracy, ICT, and oral communication for adults. Numerous online tutorials, and certain MOOC platforms such as FutureLearn, offer free or freemium classes on how to better prepare for interviews and how to apply for a job.[64]

The development of platforms and other remote working tools, such as online help desks, videoconferences, and simultaneous shared access to documents, can have an impact on well-being by allowing many more people not only to find work but also to work flexibly, as best suits their needs.

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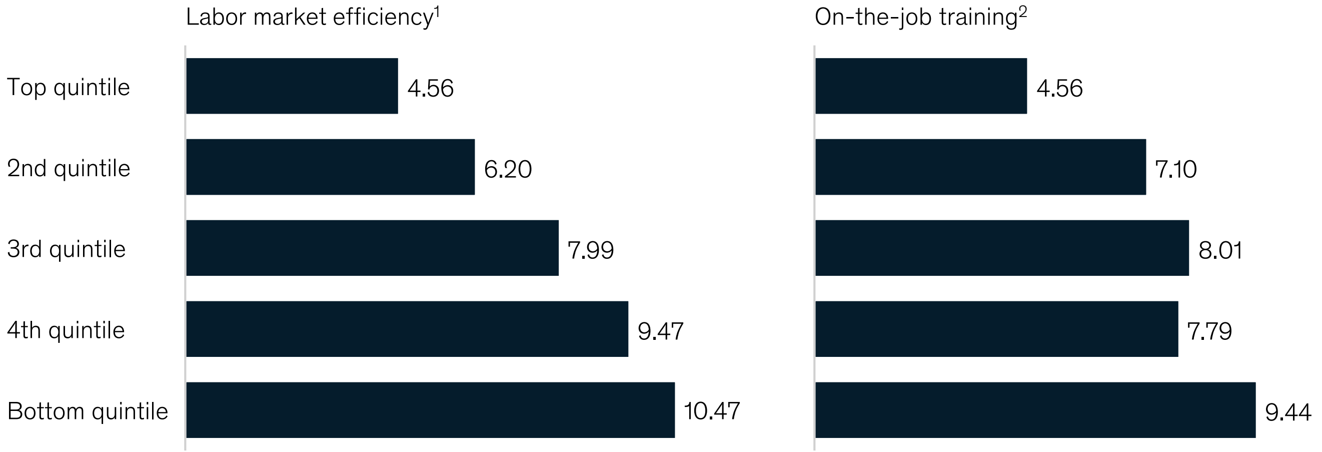
60 *A future that works: Automation, employment, and productivity*, McKinsey Global Institute, January 2017.
61 Doing Business, World Bank.
62 *A labor market that works: Connecting talent with opportunity in the digital age*, McKinsey Global Institute, June 2015. Other research amplifies the significance of better talent matching for firm productivity and wage premiums. See Stephan Bender et al., *Management practices, workforce selection, and productivity*, CEP discussion paper 1316, March 2016.
63 Chris Cornwell, Ian Schmutte, and Daniela Scur, *Building a productive workforce: The role of structured management practices*, Royal Economic Society conference paper, April 2019; *The Great Divergence(s): The link between growing productivity dispersion and wage inequality*, STI Policy Note, May 2017.
64 See "About Skills Norway," Kompetanse Norge, kompetansenorge.no/English/About-Skills-Norway/; "About FutureLearn," FutureLearn, futurelearn.com/about-futurelearn.

Exhibit 11

Labor market flexibility and on-the-job training are associated with lower unemployment.

Harmonized unemployment rate in OECD countries, 2007–17,
Average unemployment rate in each quintile, % of workforce



1 World Economic Forum labor market efficiency indicator.
2 World Economic Forum on-the-job training indicator.
Source: World Economic Forum Competitiveness Index 2017–18; OECD; McKinsey Global Institute analysis

Theme 2: Material living standards

As with job security, automation and AI could have a negative effect on material living standards if adoption leads to job losses with resulting loss of income. At the same time, technology can improve material living standards, including through generating new sources of income. Digital platforms, for example, are already enabling a new generation of “micromultinationals” to sell goods and services to a global audience.[65] Technology can also ease access to financing, reduce costs of goods and services ranging from food to travel, and improve social transfer models, such as through digital ID programs.

Income is an important driver of welfare.[66] Indeed, having sufficient income to live comfortably and afford more than basic necessities is a classic middle-class aspiration around the world, and often includes the desire to be able to afford a home, a car, and other material goods.

Polls today show that many middle-class and working-class people in advanced economies feel that their incomes have become stuck—and that the future may only get worse. This perception is reinforced by a decoupling that is taking place in countries including the United States, where median wage growth is lagging behind growth in economic activity; the share of income going to labor in the US private business sector declined by about 5.4 percentage points between the periods 1998 to 2002 and 2012 to 2016.[67] At the same time, rising costs of healthcare, education, and housing in many countries have contributed to the feeling that people are worse off.

How much technology is to blame for these changes is a subject of intense academic debate, with some of the literature highlighting the role of automation in the decreasing labor share of income, for example.[68] Our research has shown that many middle-wage jobs in advanced economies are dominated by highly automatable activities in fields such as manufacturing and accounting, the demand for which is likely to decline. High-wage jobs, especially for high-skill medical and tech or other professionals, will see significant growth in demand. However, many of the other jobs expected to be created, such as construction workers and nursing aides, typically have lower wage structures.[69] At the same time, technologies including AI have the potential to significantly boost living standards, even if that potential may not materialize at the broader economic level until these technologies are widely diffused into new productive activities.[70]

Our research suggests that the new generation of smart technologies could not only raise efficiency but lift the level of innovation—and those innovations could materially go beyond income growth to build a better life. One way in which technology can support innovation is by developing platforms of local ecosystems of smaller firms. Another is to create data lakes

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

66 In the literature, the relationship between income and well-being has been intensely discussed since a paper by Richard Easterlin found that, paradoxically, while richer individuals were happier than those with lower incomes, there was no evidence to suggest that average happiness increased over time in line with increased GDP. Richard A. Easterlin, “Does economic growth improve the human lot? Some empirical evidence,” in *Nations and households in economic growth: Essay in honor of Moses Abramovitz*, Paul A. David and Melvin W. Reder, eds., New York, NY: Academic Press, 1974.

67 *A new look at the declining share of labor income in the United States*, McKinsey Global Institute, forthcoming.

68 The role of automation in the decreasing labor share of income is a lively discussion in the literature, with the main debate being about the scale and timing of the effects of globalization. Other factors, including higher depreciation due to a shift to more intellectual property and other intangible capital, a “winner-takes-most” dynamic in some sectors, and declining union bargaining power, also play a role. See, for example, Daron Acemoglu and Pascual Restrepo, *Robots and jobs: Evidence from US labor markets*, NBER working paper number 23285, 2017; David Autor, *The polarization of job opportunities in the U.S. labor market: Implications for employment and earnings*, Center for American Progress, 2010; Virginia Eubanks, *Automating Inequality: How High-Tech Tools Profile, Police, and Punish the Poor*, New York, NY: St. Martin’s Press, 2018; Lawrence Mishel and Josh Bivens, *The zombie robot argument lurches on*, Economic Policy Institute, May 24, 2017.

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

70 We estimate that at the global average level of adoption and absorption implied by a previous simulation, AI has the potential to deliver additional global economic activity of around $13 trillion by 2030, or about 16 percent higher cumulative GDP compared with today. This amounts to 1.2 percent additional GDP growth per year. *Notes from the AI frontier: Modeling the impact of AI on the world economy*, McKinsey Global Institute, September 2018.

that can be shared for fundamental innovative research, as is happening already with some genome research and climate science.[71]

Technology can also enable digital business models that raise incomes through better innovation. Connectivity platforms such as eBay and Etsy, among others, allow individuals and small businesses to generate additional sources of income with lower intermediation costs than traditional retail channels. Individuals including those without steady work can directly see the gain from their work, which can also be a source of satisfaction.[72] Moreover, independent workers can use digital platforms to earn income. In prior work, we have estimated that, by 2025, online talent platforms could enable as many as 60 million people find work that more closely suits their skills or preferences and reduce the cost of human resources management, including recruitment, by as much as 7 percent (Exhibit 12).[73] Surveys we have conducted show that independent workers out of choice tend to have high levels of satisfaction—higher even than those in traditional jobs by choice.[74]

Financing can also be easier. Mobile payment technology has given millions of previously "unbanked" people access to financial services, especially in emerging economies, and much more can still be done. The M-Pesa mobile-money system in Kenya is often cited as an example—the share of adults in Kenya using it grew from zero to 40 percent within its first three years of launching in 2007.[75] M-Pesa's rise has spawned other innovative schemes that help low-income households. However, the role of the right policy environment in the case of M-Pesa also should not be overlooked: no other developing country has achieved the same outcomes as Kenya.

[71] See, for example, Vishal Puri, "Disrupting the high-end Genomics data processing industry with cloud economics," *Medium*, July 23, 2018; Mohana Ravindranath, *White House unveils data sharing platform for climate change research*, NextGov, September 22, 2016.
[72] *Independent work: Choice, necessity, and the gig economy*, McKinsey Global Institute, October 2016.
[73] *A labor market that works: Connecting talent with opportunity in the digital age*, McKinsey Global Institute, June 2015.
[74] *Independent work: Choice, necessity, and the gig economy*, McKinsey Global Institute, October 2016.
[75] *Digital finance for all: Powering inclusive growth in emerging economies*, McKinsey Global Institute, October 2016.

Exhibit 12

A significant proportion of independent workers have used digital platforms to earn income.

Responses to MGI survey, United States and EU-15

	Population, Millions of people	Share that have earned income from a digital platform, %	Number of digital platform users, Millions of people	Example platforms
All independent workers	162	15	24	• Freelance Physician • Deliveroo • TaskRabbit • Uber • Upwork
Independent workers who provide labor	150	6	9	
Independent workers who sell goods	21	63	13	• Etsy • eBay
Independent workers who lease assets	8	36	3	• Airbnb • Boatsetter • Getaround • BlaBlaCar

1 EU-15 based on population-weighted extrapolation from five countries surveyed: France, Germany, Spain, Sweden, United Kingdom.
Note: Survey was run in 2016. An individual may participate in multiple forms of independent earning. Therefore the three categories sum to greater than the total population of independent workers.
Source: OECD; McKinsey Global Institute analysis

Advanced analytics and platforms allow for alternative credit-scoring systems, ensuring that more capital can be funneled to individual or social projects that would not otherwise have access to financing. For example, Lenddo makes use of metrics it gathers from social websites, such as Yahoo, Google, LinkedIn, Twitter, and Facebook, to assess a consumer's potential to pay off loans. It then offers underwriting information to lenders.[76]

Technology can improve material living standards in other ways. Automation can lower costs as productivity rises, allowing firms to pass on savings to consumers. Clothing prices, for example, have dropped by about 10 percent since 1998.[77] Platforms can also help reduce the bill for essential goods, including education, housing, and electricity, by allowing consumers to find affordable goods and services. For example, the French site CrossShopper and others offer deals to customers by matching prices of all local retail competitors and major online competitors, and they allow easy switching between providers (including utilities). Expedia and other sites such as SkyScanner do the same for airline tickets.

Platforms have given rise to entirely new types of businesses such as online food delivery companies. Deliveroo and Foodora, among others, allow consumers to compare offerings and order meals from a group of restaurants through a single website or app; McKinsey estimates that the addressable market for food delivery could exceed $20 billion by 2025.[78]

Technology can also be used as a tool to make housing more affordable. Worldwide, MGI has estimated that some 330 million urban households currently live in substandard housing or stretch to pay housing costs that exceed 30 percent of their income.[79] Creating open-source maps of all city land parcels overlaid with development opportunities can foster debate about priorities. Tools such as Owlized can help residents visualize proposed projects in their neighborhood in 3-D. Cities can use digital tools to streamline their processes to fast-track land-use approval and permitting, creating a more predictable and less burdensome process. Technology can also lower the cost of construction, improving the accuracy of cost and schedule estimates as well as engineering productivity. Advanced automated equipment, such as bricklaying and tiling robots, can accelerate on-site execution.[80]

Finally, technology can optimize social transfer models. Mobile internet and connectivity platforms allow greater reach of social services, leveraging high internet penetration to distribute social support. Digital IDs allow people everywhere who lack a legally recognized form of identification to gain access to banking, government benefits, education, and other critical services. India currently is testing the world's largest biometric ID scheme, with 1.2 billion Indians already enrolled. While the results of the scheme remain to be seen, its goal of direct depositing of welfare payments to digital bank accounts has the potential to reduce fraud in addition to improving convenience.[81]

[76] Tom Groenfeldt, "Lenddo creates credit scores using social media," *Forbes*, January 29, 2015.
[77] US Bureau of Labor Statistics.
[78] Carsten Hirschberg, Alexander Rajko, Thomas Schumacher, and Martin Wrulich, *The changing market for food delivery*, McKinsey & Company, November 2016.
[79] *A blueprint for addressing the global affordable housing challenge*, McKinsey Global Institute, October 2014.
[80] *Housing affordability: A supply-side tool kit for cities*, McKinsey Global Institute, October 2017.
[81] *Digital identification: A key to inclusive growth*, McKinsey Global Institute, April 2019; *Digital India: Technology to transform a connected nation*, McKinsey Global Institute, March 2019.

Theme 3: Health and longevity

Our use-case library highlights technology's significant potential to improve health. The possibilities range from AI-powered drug research, which is pushing the frontiers of drug discovery, to personal lifestyle wearables that can help individuals monitor their health and track improvements. Technology can also ease access to health, including through telemedicine, and create new efficiencies and reduce waste in healthcare systems, whose rising costs are increasingly affecting living standards and putting pressure on public finances in some countries.

Living a healthy and long life is an essential contributor to well-being. Our welfare estimates in the next chapter confirm health as a critical factor affecting the overall outcome, in line with previous research on welfare that shows how a large part of welfare growth is driven by an increase in longevity and health.[82] Technology has been a key enabler of this increase over the past century or more.[83]

The potential of some technologies to help diagnose, cure, or treat acute diseases is one of the most exciting areas of research.[84] AI is proving to be a particularly powerful tool for innovation. For example, a UK-based startup that has partnered with several large drug makers, Exscientia, applies AI capabilities to test new drug molecules based on massive data sets. This allows drug makers to experiment with products based on similar molecules, speeding up drug development while reducing cost. Other AI startups are also pairing up with large pharma firms.[85]

Cell therapy (the transfer of intact, live cells into a patient to help alleviate or cure a disease) and gene therapy (a technique that modifies a person's genes to treat or cure disease) are also expected to experience rapid growth in the next five to ten years.[86] In addition to the already publicized treatments of some types of cancer and diabetes, technology advances could reap benefits in the fight against other major diseases. AI already shows results in applications ranging from diagnosis of pneumonia, malaria, or Alzheimer's to prediction of strokes and heart attacks, or of autism in infants. Robotics, meanwhile, has potential in surgery.[87]

Tracking capabilities of some applications can also be used effectively in health. In the case of epidemics, for example, advanced analytics and predictive models can help identify transmission routes and prevent transmission in the most efficient way possible. One example of the potential of tools in this opportunity area is Artificial Intelligence in Medical Epidemiology, an AI-enabled platform that helps a country's ministry of health predict future outbreaks of diseases like Zika and dengue in a specific geography months before their possible occurrence. It also helps the ministry select the most appropriate vector control method to prevent the outbreak. While the platform is an early-stage Silicon Valley venture and its technologies and tools have not been validated at scale, its work reflects the potential of AI predictive analytics tools in global health.[88]

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82 See Charles I. Jones and Peter E. Klenow, "Beyond GDP? Welfare across countries and time," *American Economic Review*, September 2016, Volume 106, Number 9; Kevin M. Murphy and Robert H. Topel. "The value of health and longevity," *Journal of Political Economy*, 2006, Volume 114, Issue 5.

83 Daniel Gallardo-Albarrán, "Missed opportunities? Human welfare in Western Europe and the United States, 1913–1950," *Explorations in Economic History*, 2018.

84 See, for example, Frank R. Lichtenberg, "The impact of biomedical innovation on longevity and health," *Nordic Journal of Health Economics*, 2017, Volume 5, Number 1.

85 See Exscientia's website, exscientia.co.uk/. For additional examples, see HealX, which offers an AI-based drug discovery platform applied to a wide range of data types, used for developing rare disease treatments (healx.io/), and Iqvia, a company offering clinical trial, drug development, and commercialization solutions based on advanced analytics and machine learning, with the aim of accelerating the entire drug R&D process (iqvia.com/).

86 *Helping to accelerate cures: Regulating the rapidly evolving field of cell and gene therapies*, McKinsey & Company, January 2019.

87 See Dave Gershgorn, "Stanford trained AI to diagnose pneumonia better than a radiologist in just two months," Quartz, November 16, 2017; Jeremy Hsu, *AI-powered microscope counts malaria parasites in blood samples*, IEEE Spectrum, November 13, 2017; Dana Smith, *Artificial Intelligence can detect Alzheimer's disease in brain scans six years before a diagnosis*, University of California San Francisco, January 2, 2019; Eliza Strickland, *AI predicts heart attacks and strokes more accurately than standard doctor's method*, IEEE Spectrum, May 1, 2017; Megan Scudellari, *AI predicts autism from infant brain scans*, IEEE Spectrum, February 15, 2017; Eliza Strickland, *In flesh-cutting task, autonomous robot surgeon beats human surgeons*, IEEE Spectrum, October 13, 2017.

88 Julian Furtkamp, "Could artificial intelligence help us predict the next epidemic?" *Reset*, June 27, 2017.

Technology can have negative effects on health, including contributing to a more intense workplace with higher levels of stress. Nevertheless, technology itself provides opportunities to reverse negative health outcomes at work. One way is through improved safety: using sensors and tags, IoT technology can help improve health and safety management in oil and gas, reducing accidents and injuries and the cost of insurance by 10 to 20 percent.[89]

Moreover, selective automation, augmented reality at work, and a range of feedback tools can boost satisfaction and give more meaning to work. This is a particularly important element for the millennial generation, which tends to put more emphasis on work satisfaction than on income (above a certain income level), according to surveys.[90] Companies deploying such technologies with the goal of increasing satisfaction include Humu, which uses data analytics to identify behavioral changes that are likely to make the biggest impact on raising the happiness level of workers. Then it uses emails and text messages to "nudge" individual employees into small actions that advance the larger goal.[91]

So-called serious games are increasingly used by companies to train their workforce and increase overall well-being at work. For example, Curapy creates therapeutic games tackling mental health, temporary mobility impairment, first aid training, and other topics.

At a personal level, lifestyle wearables and fitness trackers could contribute to improving health for many individuals.[92] Beyond these lifestyle tools, technology can help healthcare professionals monitor patients on a continuous basis—for example by providing blood glucose readings—remotely. One example is Boston-based Partners Healthcare, which used at-home monitoring devices to track weight, blood pressure, and other metrics for 3,000 congestive heart failure patients. The program reduced hospital readmissions among the participating patient population by 44 percent while generating cost savings of more than $10 million over a six-year period.[93]

Medication adherence technologies assist patients in taking drugs as recommended by their healthcare provider through smart pill bottles, ingestible sensors, and peer-to-peer reminders that monitor and promote adherence to doctors' orders to increase medication efficacy and provide data for enhanced R&D and marketing. This is especially relevant for elderly populations that may need reminders to take medications at the right time and the right dosage. Similarly, the ability to monitor and track can be used to predict premature labor via blood testing and DNA decoding, potentially reducing infant mortality.

Another potential use of technology is to help reduce inequality of access to healthcare, in developing countries as well as for the underserved in developed countries. Real-time remote interaction between healthcare providers and patients through the use of audiovisual communication tools helps the elderly or underserved in rural areas, for example, gain access to expert specialist consultations for low-acuity conditions. Wagner Community Memorial Hospital and St. Andrews Health Center are among hospitals that are implementing an emergency care program under which board-certified emergency department physicians deliver immediate, supportive care to emergency departments at more than 100 hospitals. Individual providers use this service when local emergency department providers are not available.

One example of a patient-facing AI tool is Babyl, which operates in certain developing geographies such as Rwanda. Developed in the UK, it provides an integrated AI platform for patients, including an AI triage symptom checker, health assessment, and virtual consultations with a physician when referral is needed.[94]

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[89] *The internet of things: Mapping the value beyond the hype*, McKinsey Global Institute, June 2015.
[90] See, for example, *Purpose at work: 2016 global report*, LinkedIn.
[91] Daisuke Wakabayashi, "Firm led by Google veterans uses A.I. to 'nudge' workers toward happiness," *New York Times*, December 31, 2018.
[92] See Enrique Dans, "Insurance, wearables and the future of healthcare," *Forbes*, September 21, 2018; Lukasz Piwek et al., *The rise of consumer health wearables: Promises and barriers*, PLOS, February 2, 2016.
[93] Joseph Kvedar, Molly Joel Coye, and Wendy Everett, "Connected health: A review of technologies and strategies to improve patient care with telemedicine and telehealth," *Health Affairs*, February 2014, Volume 33, Number 2.
[94] *Artificial intelligence in global health: Defining a collective path forward*, USAID.

Finally, technology can be an important tool for improving public health by bringing greater efficiency to complex health systems. For example, staff members at Hospital Estadual Getúlio Vargas, a public hospital that serves citizens in Rio de Janeiro, are using advanced analytics to help improve patient care and treatment. The team has shortened the length of stay for ICU patients by just over three days.[95]

Healthcare expenditure in OECD countries has been rising at a rate one to two percentage points faster than GDP in recent years, and health outcomes vary widely across healthcare systems and among the care providers. For instance, maternal mortality is 4.0 per 100,000 births in Italy, but more than six times higher in the United States, at 26 per 100,000 in 2015. Postoperative pulmonary embolisms and thrombosis affect 865 of every 100,000 patients leaving a hospital in France, but just 107 in Belgium, a difference of 706 percent.[96]

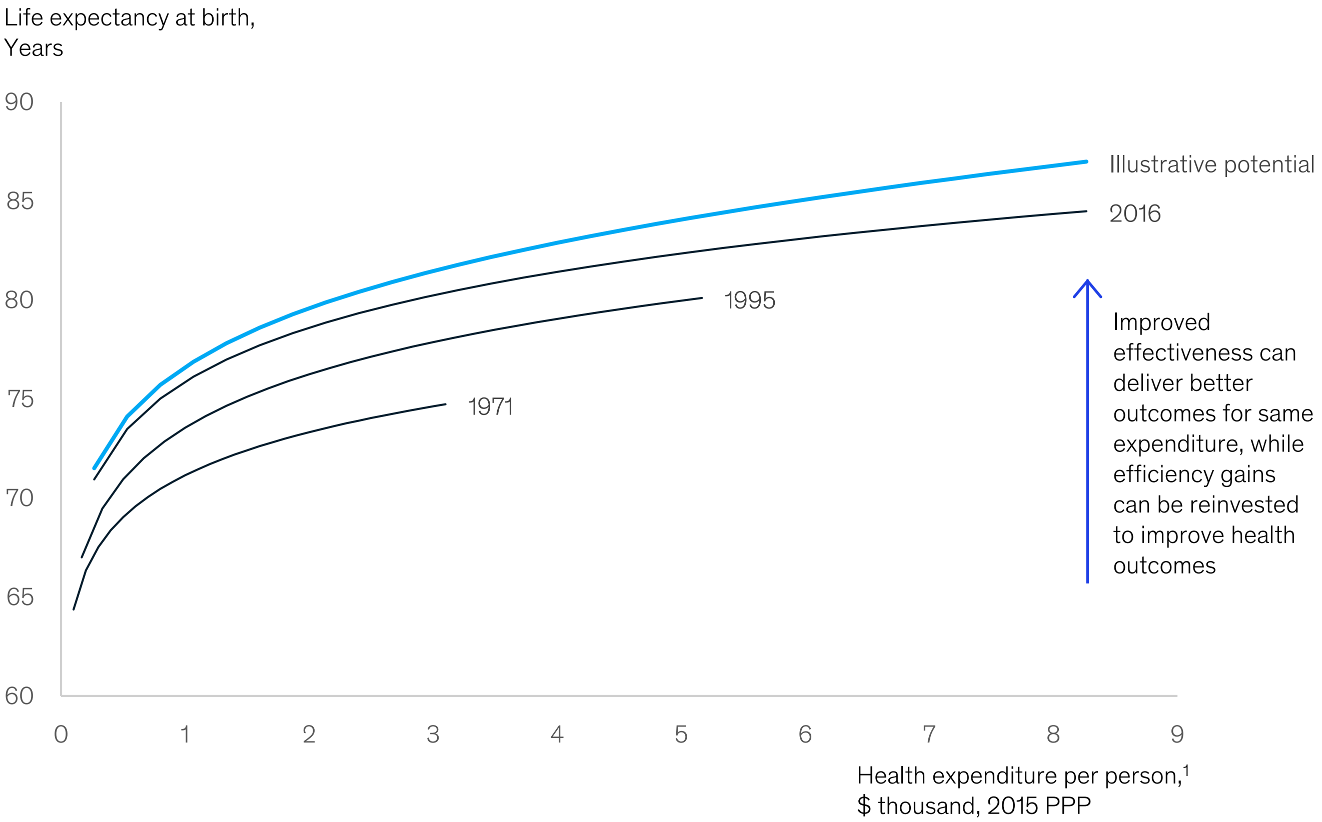
The relationship between health expenditure and life expectancy across OECD countries indicates two ways in which technology can boost public health delivery. First, if technology allows health systems to become more efficient, the money saved can be reinvested for better health outcomes. Second, as has historically been the case, technology can shift the whole curve upward, allowing better health outcomes to be delivered for each dollar spent. The second phenomenon is clearly visible in historical data (Exhibit 13). Of course, many factors, including living conditions and diet, have contributed to this shift, but technology has also played a major role.

[95] Sean Dudley, "Brazilian hospital uses analytics to improve ICU treatment for patients," *Record*, October 22, 2015.
[96] Thomas London and Penelope Dash, *Health systems: Improving and sustaining quality through digital transformation*, McKinsey & Company, August 2016.

Exhibit 13

Technology has the potential to enhance health through both efficiency and effectiveness.

Historical relationship between health expenditure and outcomes in OECD countries,[2] 1971–2016



[1] Includes both private- and public-sector expenditure on health.
[2] Lines shown represent power curves with best fit; R^2 is 0.47, 0.70, and 0.62 for 1971, 1995, and 2016 respectively.
Source: OECD; McKinsey Global Institute analysis

Theme 4: Education

Education is a critical enabler of positive welfare outcomes, as it increases the prospects for a better job and higher income. In a new era of automation and AI adoption, education will be a decisive tool to ensure that future generations are equipped with the skills they need for an evolving world of work. That in turn will have significant ramifications on both job security and material living standards and can help improve mobility and mitigate rising inequality.

In our use-case library, we find a range of ways in which the latest technologies can play a positive role in education, including by improving access to and the quality of education overall, and the efficiency of learning tools. Use cases include attempts to create online apprenticeship tools and AI-powered adaptive learning tools that adjust based on the abilities and progress of each student.

School systems and curricula will need to change, with a reinforced emphasis on science, technology, engineering, and mathematics (STEM). Other skills, which are not currently part of the curriculum, will also be in demand. For example, the need for social and emotional skills, including empathy, adaptability, the ability to negotiate, entrepreneurship, and initiative taking, will experience a steep increase in demand, based on our research. Basic literacy and numeracy will no longer be enough for the jobs of tomorrow. The share of jobs requiring performance of simple repetitive tasks will shrink in years to come.[97]

In terms of access, global government expenditure on education in high-income countries only marginally increased in the period from 2013 to 2015, from 5.0 to 5.3 percent of GDP. At the same time, spending on education as a share of GDP declined among the 28 EU nations, from 5.1 percent in 2003 to 4.6 percent in 2017.[98]

Global K-12 education spending more than doubled from $1.2 trillion in 2002 to $2.8 trillion in 2016, but the outcomes can be disappointing. In England, for example, about 150,000 children leave primary school every year unable to read well. This includes one-third of all children growing up in poverty. One UK nonprofit, Brightside Trust, seeks to address this problem through a digital platform that matches students with mentors; about 100,000 students have already been paired in this way.[99] Other nonprofits seek to equip young people with skills they will need in the workplace and link them to potential employers.[100]

Online education platforms can provide students with a high-quality education at low cost. MOOCs such as Coursera and MIT OpenCourseWare for now largely cater to an already educated public, but some startups are using them in innovative attempts to help those in need. For example, Kiron, a German online platform recognized by UNESCO, provides blended-learning higher education for refugees worldwide regardless of their asylum status.[101]

Technology can help support educational capacity, for example with virtual classrooms increasing the accessibility and scalability of lectures, and can allow for more personalized and flexible education models. Kennisnet, in the Netherlands, has provided virtual education since 2005, and the Koulu 360 initiative in Finland aims to develop the country's first virtual school.[102]

For its part, AI could become a valuable tool for teachers, with functions including grading. One company, GradeScope, uses computer vision and machine learning to grade students' work

97 See *Skill shift: Automation and the future of the workforce*, McKinsey Global Institute, May 2018.
98 Data from World Bank and Eurostat.
99 Brightside website, brightside.org.uk/what-we-do/track-record; *Ready to read*, UK Department for Education, National Literacy Trust, 2015.
100 McKinsey founded one such nonprofit, Generation, which has trained and placed more than 25,000 young people in jobs with 2,600 employers over the past four years. www.generation.org.
101 "UNESCO prize-winning platform gives education, integration and hope to refugees," UNESCO, February 2, 2017.
102 *Notes from the AI frontier: Tackling Europe's gap in digital and AI*, McKinsey Global Institute, February 2019.

quicker than a teacher, starting by deciphering handwriting and remembering the teacher's initial decisions on marks to automatically grade subsequent students. For now, it can work on topics including computer science and economics with objectively correct answers.[103]

Improving the quality and relevance of education is also an area where technology is making inroads. Studies such as the OECD's PISA surveys highlight stagnating education outcomes in advanced economies, in a context of constrained or decreasing government expenditure on education and worker training.[104] Critically, the passage from education to employment remains challenging in many countries, with a mismatch between the skills acquired by young people and available jobs. In one survey, 39 percent of employers said that a skills shortage is a leading reason for entry-level vacancies.[105] Together with data analytics, AI can forecast job demand, helping education providers tailor their offerings to the future labor market. Digital technologies are already making a difference by connecting talent with opportunities in the job market.

Technological applications can also improve the efficiency of learning tools. This is not new, of course: overhead projectors, photocopiers, and calculators have all found their place in the classroom over the past decades, and new digital tools are also being integrated into curricula and daily practices. While most technologies historically focused on improving teacher workflow, the latest suite of digital applications helps students obtain feedback and has spawned a new generation of technology-reinforced personalization in the classroom.[106]

Examples of this range from using chatbots in the classroom to ask for student feedback and even substitute for a university teaching assistant, as Georgia Tech has done, to more sophisticated programs of adaptive learning that adjust teaching to the abilities of individual students, and could be used to help children with learning disabilities.[107] AI tools, for example, can help students explore and determine how best they learn, and adapt tests to their level so that they can always progress.

Technology in the classroom has a mixed track record, however. Studies have shown that investing heavily in school computers and classroom technology does not always improve pupils' performance. The best results come when technology is placed in the hands of teachers.[108]

Technology not only increases the efficiency of the existing educational approaches but facilitates experimentation with pedagogical methodologies. For example, technology is a prerequisite and enabler for the flipped classroom approach, inverting a traditional notion of classwork and homework.[109]

Finally, technology application in schools could have a more prosaic purpose and solve one pain point identified by teachers: administrative tasks, which take up between 6 and 15 percent of their time across countries.[110] Online platforms can help schools share content with students and free teachers' time by systemizing and automating administrative tasks.

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[103] *Artificial intelligence: The next digital frontier?* McKinsey Global Institute, June 2017.
[104] See "Snapshot of performance in science, reading and mathematics" in *PISA 2015 results in focus*, OECD, December 9, 2016; "Evolution of 'education' expenditure over 2003-2017" in *Government expenditure on education*, Eurostat, March 2019; and *Jobs lost, jobs gained: Workforce transitions in a time of automation*, McKinsey Global Institute, December 2017.
[105] *Education to employment: Designing a system that works*, McKinsey Center for Government, 2015.
[106] See Barbara Means, Vanessa Peters, and Ying Zheng, *Lessons from five years of funding digital courseware: Postsecondary success portfolio review*, SRI Education, September 2014; David Nitkin, "Technology-based personalization: Instructional reform in five public schools," Columbia University, May 2018; Anya Kamenetz, "The future of learning? Well, it's personal," NPR, November 16, 2018.
[107] *Notes from the AI frontier: Applying AI for social good*, McKinsey Global Institute, October 2018.
[108] *Students, computers, and learning*, OECD 2015; Mona Mourshed, Marc Krawitz, and Emma Dorn, *How to improve student educational outcomes: New insights from data analytics*, McKinsey & Company, September 2017.
[109] See K.S. Chen, *Academic outcomes of flipped classroom learning: A meta-analysis*, Medical Education, June 25, 2018.
[110] McKinsey Global Teacher and Student Survey, January 2018.

Theme 5: Environmental sustainability

The increasing depletion of natural resources and rising incidence of extreme weather conditions and growing pollution in oceans and elsewhere make for daily headlines around the world and growing calls for action.

Technology contributes to energy use, evidently; according to various estimates, the world's ICT ecosystem uses about 1,700 terawatt-hours of electricity annually, or about 8 percent of all global usage.[111]

Technologies have multiple roles to play in improving sustainability. First, they can help reduce air and water pollution by curbing current pollution sources and preventing future pollution. They can limit some of the contributors to climate change, including through energy efficiency and renewable energy sources. They can reduce waste through more efficient recycling and other measures. Finally, they have the potential to conserve biodiversity, including through AI-powered monitoring of land and sea, and through their potential contribution to sustainable and productive food systems.

Managing urban pollution will be key in a world projected to have 43 megacities with more than 10 million inhabitants in 2030.[112] AI-based traffic management in cities, including optimizing traffic light networks to improve the flow of cars and trucks, can reduce the impact of pollution on health by between 3 and 15 percent.[113] In our research, we have found that using the current generation of smart city applications effectively could help cities make significant or moderate progress toward meeting 70 percent of the United Nations Sustainable Development Goals.[114]

Limiting climate change is a second area of technological focus, for which energy efficiency and renewable energy sources are expected to make the greatest difference. The International Energy Agency forecasts that both could contribute as much as 76 percent of the CO2 emission reductions needed to stabilize or reduce temperature increases, while still reaching the UN's Sustainable Development Goal of universal access to modern energy.[115]

Electric utilities can use smart grid technology to optimize energy efficiency by 12 to 21 percent, or $310 billion to $540 billion, between 2015 and 2035.[116] AI and IoT help reduce energy consumption through automated management of operations, while increasing factory productivity. DeepMind helped reduce the cooling bill at Google's data centers by up to 40 percent.[117] In the future, machine and deep learning technologies could forecast demand and supply in real time and optimize load dispatch, thereby saving energy and cost.[118] Already, renewable energies have made major inroads, and accounted for as much as 24 percent of global electricity in 2017.[119] Future developments will impact both developing economies and more advanced economies, where much of the technological

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111 Anders S. G. Andrae and Tomas Edler, "On global electricity usage of communication technology: Trends to 2030," *Challenges*, 2015.
112 World Health Organization air pollution data; Erik Solheim, "Creating a global pollution observatory: Battling big pollution with big data," UN Environment, September 24, 2018, unenvironment.org/news-and-stories/blogpost/creating-global-pollution-observatory-battling-big-pollution-big-data; 2018 Revision of World Urbanization Prospects, United Nations Department of Economic and Social Affairs, May 16, 2018, un.org/development/desa/publications/2018-revision-of-world-urbanization-prospects.html.
113 *Smart cities: Digital solutions for a more livable future*, McKinsey Global Institute, June 2018.
114 Ibid.
115 *Carbon capture, utilisation and storage: A critical tool in the climate energy toolbox*, International Energy Agency.
116 *Global energy perspective*, McKinsey Energy Insights.
117 *Artificial intelligence and the circular economy: AI as a tool to accelerate the transition*, Ellen MacArthur Foundation, 2019; *DeepMind AI reduces Google data center cooling bill by 40%*, deepmind.com/blog/deepmind-ai-reduces-google-data-centre-cooling-bill-40/.
118 *Artificial intelligence: The next digital frontier?*, McKinsey Global Institute, June 2017.
119 International Energy Agency.

attention is focused on energy storage solutions to optimize electricity availability. The applications will include electric vehicles but also, potentially, electric or hybrid marine transport and aviation.

Smart building technology relies on sensors and data analytics to optimize energy consumption and monitor indoor air quality for improved physical well-being, as well as new material development for carbon-neutral buildings. Companies such as Kingspan produce vacuum insulation panels that ensure a reduction in heat loss, while Saint Gobain manufactures a smart glass that can be tinted to block out light at the touch of a button.

Reducing waste is a third area where technology can have—and already is having—a significant impact. The circular economy's new services and business models, which are largely facilitated by digital platforms, could unleash as much as 1.8 trillion euros of annual benefit, or a 7 percent additional GDP increase relative to the current development scenario in Europe alone by 2030.[120] Artificial intelligence and robotics are expected to play a large role in waste processing, ranging from food to electronic waste, by increasing the productivity of solid waste pickup, screening, and pricing.[121]

A number of large consumer goods companies including Coca-Cola, Danone, PepsiCo, Unilever, P&G, and L'Oréal have committed to reducing plastic packaging or making it recyclable. Some are focusing efforts on the circular economy, which creates value and safeguards the environment by improving the management of resources, eliminating waste through better design, and maximizing the circulation of products, components, and materials in use. The potential gains for growth, household incomes, and the environment could be considerable, including a 48 percent reduction of carbon dioxide emissions by 2030 in some areas.[122] Smaller companies are developing innovative solutions; for example, Ecovative is a biotech company creating next-generation materials through biofabrication of mycelium (mushroom roots), with applications ranging from clothing to packaging, construction material, and even food products.[123]

At the city level, technologies are already being deployed to optimize waste pickup. Several cities including Pune, India, have piloted technology applications that use end-to-end automation and IoT sensors along with mobile and web applications to route collecting vehicles only if bins are 75 percent full. This has improved resource use and the city's cleanliness. In Seoul, municipal authorities equipped garbage bins with RFID sensors that weigh trash and generate a bill for each household, a scheme known as "pay as you throw."[124]

Designing AI into the food system has the potential to transform agriculture and cut out avoidable food waste. With the help of data from drones, remote sensors, satellites, and smart farm equipment, conventional practices such as mono-cropping, blanket application of synthetic chemical fertilizers, and intensive land use could be replaced with more regenerative agriculture practices. AI can also help farmers at the outset to reduce waste. Farm-based food supply chains can become more efficient using image recognition technology during food inspections. AI-enabled tracking can help retailers sell food before it goes bad, and AI algorithms can forecast and predict sales to allow restaurants and retailers to more effectively connect supply to demand when ordering food.[125]

[120] *Growth within: A circular economy vision for a competitive Europe*, Ellen MacArthur Foundation, McKinsey Center for Business and Environment, and SUN, 2015.
[121] *Artificial intelligence and the circular economy: AI as a tool to accelerate the transition*, McKinsey & Company, January 2019.
[122] *Growth within: A circular economy vision for a competitive Europe*, Ellen MacArthur Foundation, McKinsey Center for Business and Environment, and Stiftungsfonds für Umweltökonomie und Nachhaltigkeit (SUN), 2015.
[123] Ecovative, ecovativedesign.com/ourfoundry.
[124] *Smart cities: Digital solutions for a more livable future*, McKinsey Global Institute, June 2018.
[125] Clarisse Magnin, *How AI can unlock a $127B opportunity by reducing food waste*, McKinsey & Company, March 27, 2019.

Resource efficiency will also benefit from the development of new chemicals and materials, in particular by leveraging AI for R&D. For example, Citrine Platform uses algorithms and AI technology to develop new materials for high-performance applications, such as 3-D printable aerospace-grade aluminum alloys.

Finally, technology has a role to play in conserving biodiversity. AI-powered drones can help monitor wildlife parks and identify the location of poachers, and similarly monitor for illegal fishing.[126] Satellite monitoring can be used a tool against unauthorized deforestation; one nonprofit, Global Forest Watch, has an open-source web application that creates transparency about what is happening in forests worldwide for governments, companies, civil society organizations, journalists, and concerned citizens.

[126] *Notes from the AI frontier: Using AI for social good*, McKinsey Global Institute, October 2018.

Theme 6: Equal opportunities

For our library of use cases, we looked at technology's impact on five groups: women; minorities; people with physical or mental disabilities; the lesbian, gay, bisexual, transsexual, and intersexual (LGBTI) communities; and the elderly. In their own ways, each faces a number of challenges related to equality. They include access to essential services, enablers of economic opportunities such as finance, and suitable products, legal rights, policies, and social norms supporting an open and inclusive culture, as well as the management of physical or emotional risks that can be specifically linked to a person's abilities, gender, race, or sexual orientation.

Technologies can exacerbate inequality due to their skill-biased nature. If minorities are also underrepresented in those skill categories that are most complementary to technology, their wages are likely to be depressed. For example, the ICT sector is characterized by a substantial gender gap. A recent study found that, in Europe alone, more than three times as many men work in the digital sector as women, and four times more men are pursuing ICT-related studies; indeed, the number of women taking up ICT-related higher education has fallen since 2011.[127]

Diversity and inclusion within societies are increasingly recognized as keys for equality at work and in economic development.[128] Previous research by MGI has established a strong link between gender equality in society, attitudes and beliefs about the role of women, and gender equality in work. We have estimated that narrowing the gender gap to match the rate of improvement of the best-performing country in a region would add as much as $12 trillion in annual 2025 GDP, the equivalent to the current GDP of Germany, Japan, and the United Kingdom combined. To reach economic parity, countries need to improve women's access to education, and other factors such as childcare, to enable three key channels: greater female labor force participation, greater share of women in high-productivity sectors, and an increased share of women in high-paying occupations.[129]

The lack of equality at work is one of the most measurable forms of discrimination, as it translates into participation, equal pay, attribution of high-productivity jobs, and equality in non-market economy work. Women constitute a 50 percent share of the working-age population but on average hold only about one-third of the managerial positions available; in some countries that share drops to below 10 percent.[130] As of January 2019, women held only 21 percent of board seats, and accounted for only 5 percent of CEOs, of S&P 500 companies. When compounded with ethnic discrimination, these figures appear more daunting; women of color represented only about 5 percent of senior management positions, versus 22 percent for white women. Nonetheless, our research consistently points to correlations between levels of gender and cultural and ethnic diversity and financial outperformance.[131]

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[127] *Women in the digital age*, European Commission, March 2018.

[128] We define diversity as the quantitative share of individuals representing minorities (gender, ethnicity, age, sexual orientation, disabilities, and so forth) within an organization or a society. Inclusion refers to the degree to which employees or citizens perceive that they are accepted members of the workforce. Regarding the link between gender equality and economic development, see Sara Fisher Ellison and Wallace P. Mullin, "Diversity, social goods provision, and performance in the firm," *Journal of Economics and Management Strategy*, summer 2014, Volume 23, Number 2; Joshua Eastin and Aseem Prakash, "Economic development and gender equality: Is there a gender Kuznets curve?," *World Politics*, January 2013, Volume 65, Issue 1; David Cuberes and Marc Teignier, *Gender gaps in the labor market and aggregate productivity*, Sheffield Economic Research Paper number 2012017, June 2012; and Olivier Thévenon et al., *Effects of reducing gender gaps in education and labor force participation on economic growth in the OECD*, OECD Social, Employment and Migration working paper number 138, December 2012.

[129] *The power of parity: How advancing women's equality can add $12 trillion to global growth*, McKinsey Global Institute, September 2015.

[130] *Quick Take: Women in Management*, Catalyst, July 30, 2018.

[131] *Pyramid: Women in S&P 500 Companies*, Catalyst, January 16, 2019; *Delivering through diversity*, McKinsey & Company, January 2018.

Technologies can improve equality at work, including by revealing pay gaps and biases and helping de-bias recruitment. One startup, Textio, is using machine learning to debias job announcements that could appeal more to men than women. One of its clients, Vodafone, saw a 7 percent increase in female recruits since it started scanning ads and rephrasing them to attract female talent.[132] Slack has targeted interventions at all states of the hiring process, including ensuring that job descriptions use unbiased language, determining in advance the specific set of skills and qualities required, and giving interviewers practice with current employees to hone skills and learn to avoid biases.[133]

One UK-based company, Gapsquare, provides instant reports of pay gaps across an organization along with insights that help explain the gaps. SAP uses people analytics tools that can track diversity and detect unfairness at work, including unfair performance ratings. It is currently conducting an external audit of pay equality to analyze and achieve parity in France, using a data-driven approach to the analysis of pay discrepancy to achieve true pay parity, regardless of gender.

Technologies can also improve equal access to essential services. For example, mobile and agency banking, biometrics, and cloud technology can all contribute to increasing the diffusion of microfinance to women and underserved populations. Regarding healthcare, text-message platforms and apps provide education and awareness on maternal health information or advise on contraception and family planning methods to manage and control risks related to complicated pregnancy. A USAID program in Bangladesh, India, Nigeria, and South Africa implemented a Mobile Alliance for Maternal Action approach, which uses age- and stage-based messaging directed toward pregnant women, new mothers, and families to foster behavior change and improve maternal and child health outcomes.[134]

Some specific products improve access for particular groups. For example, Hoobox Robotics has developed a wheelchair that can be controlled by facial expressions, facilitating mobility using AI technology.[135] Affectiva, which was spun out of the MIT Media Lab, and Autism Glass, a Stanford research project, use AI to automate the recognition of emotions and provide social cues to help individuals along the autism spectrum interact in social environments.[136]

Technology is also a tool that can help enforce inclusive legal rights, policies, and social norms. While e-voting still poses a number of cyber-security challenges, one study shows its potential to support diversity by facilitating the vote of vulnerable or marginalized parts of society.[137] Digital platforms and social networks can also be used to share positive narratives and support minorities; digital media played a substantial role in raising overall awareness about the sexual harassment of women in developed countries through the #metoo movement, for example.

Finally, technology can help with physical security and autonomy for minority groups through objects and digital communications tools that reduce or mitigate exposure to risk. Connected devices such as smart bracelets can enable women to signal an assault and call for help. Leaf Wearable, for example, is an Indian startup selling jewelry that has "SOS" buttons that send alerts to a network of community responders.[138] Analytics tools such as Intel's Hack Harassment program can help identify cyberbullying.[139]

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[132] Jane Bird, "How the tech industry is attracting more women," *Financial Times*, March 9, 2018.
[133] Jessica Nordell, "How Slack got ahead in diversity," *Atlantic*, April 26, 2018.
[134] Mobile Alliance for Maternal Action (MAMA) Lessons Learned Brief, USAID Maternal and Child Survival Program, November 2017. See also *Innovations and Technology*, FINCA; *Advans Côte d'Ivoire, an Ivorian microfinance institution, wins the European Microfinance Award for "Financial Inclusion through Technology,"* European Microfinance Platform, 2018.
[135] Jason Fell, "All you need to control this wheelchair is your face," *Entrepreneur*, May 11, 2016.
[136] *Notes from the AI frontier: Applying AI for social good*, McKinsey Global Institute, October 2018.
[137] Shamika Ravi, Sisir Debnath, and Mudit Kapoor, *The impact of electronic voting machines on electoral frauds, democracy, and development*, Brookings Institution, March 20, 2017.
[138] Lori Ioannou, "$1 million Women's Safety XPrize to tackle sexual violence awarded to Indian startup," CNBC, June 7, 2018.
[139] "Hack Harassment announces formation of advisory board to elevate the dialogue around online harassment," Intel, May 2017.

4. Modeling scenarios of the welfare effects of technology adoption

The historical lessons and research we discuss in chapter 1, and the use cases we outlined in chapter 3, illustrate that technologies have multiple effects, some positive, some negative. The disruptions that technology transitions create are real, but technology could also be deployed to improve individual and societal well-being and mitigate transition risks.

These observations raise a bigger question: what would be the outcome of a concerted attempt to adopt technology in a way that is most beneficial to business and the economy and, simultaneously, to manage that adoption to maximize its social benefits and minimize the disruption and welfare losses it could cause?

This research is an early attempt to quantify the effects of the adoption of new frontier technologies on welfare, including but going beyond GDP. It builds on our earlier work from our "Notes from the AI frontier" series on the benefits and risks of those technologies. The earlier research focused on GDP, including a set of key channels through which AI can affect the performance of firms, how this creates spillovers to other economic entities, and therefore the aggregate performance of sectors and economies.[140] Our estimates of welfare growth in this paper are therefore consistent with the productivity and labor market consequences previously modeled.

For this new research, we have extended this modeling exercise to simulate the GDP and broader welfare impacts of a range of scenarios on two key dimensions: whether the primary focus of technology adoption is on cost reduction or innovation; and the degree to which governments and businesses deploy Tech for Good tools to manage the transition. The simulation covers the 28 European Union countries and the United States. In addition to the effects already captured in GDP, such as overall employment and wages, we take into account a range of other important welfare components. They include inequality, the quantity and quality of leisure, and health and longevity. Within inequality, we consider three separate elements: wage inequality, changes to the capital/labor share, and risk of unemployment. Broadening the scope of analysis in this way enables us to see technology's impacts well beyond GDP. We therefore believe that this new approach has potential to stimulate further informed debate.

We have enhanced our modeling of GDP and welfare to incorporate a number of important interactions between the key drivers. For example, a diffusion path that puts more weight on cost reduction and labor saving through automation than innovation has the effect of reducing the consumption share of income, through the increased likelihood of unemployment directly emerging from the model outcome. At the same time, technology-induced labor productivity growth could lead to a higher intensity of work, causing more stress and pressure on health. Such feedback loops provide a more complete dynamic view of how technology interacts with GDP and beyond, a feature often lacking in welfare estimates in the literature.

[140] See *Notes from the AI frontier: Modeling the impact of AI on the world economy*, McKinsey Global Institute, September 2018; *Notes from the AI frontier: Applying AI for social good*, McKinsey Global Institute, October 2018; *Notes from the AI frontier: Tackling Europe's gap in digital and AI*, McKinsey Global Institute, February 2019.

A simulation of this nature is ambitious, given the lack of academic consensus about how to do it or which assumptions to use, along with issues surrounding data availability for estimating parameters and functional forms. The findings are therefore indicative and directional rather than precise, and they should not be taken as forecasts or predictions. The results clearly depend on the factors that we include or exclude. In our modeling, we incorporate those factors that have been found to be among the largest drivers of welfare and that can be modeled robustly.[141]

When considered together with the results of our sensitivity analyses, our simulation highlights the significance of different technology adoption approaches on GDP and welfare. Outcomes diverge strongly depending on whether or not adoption is focused on innovation and growth—as opposed to labor substitution and cost reduction—and whether diffusion is accompanied by proactive measures that can smooth the transition and offset some of the negative consequences.

Our measurement of welfare

As noted in chapter 2, existing research has tried to provide a measure of welfare that incorporates factors outside GDP. Our estimates are inspired by the methodology proposed by Stanford economists Charles I. Jones and Peter E. Klenow, and informed by, among others, literature on health economics and the well-being and happiness economics championed by Richard Layard of the London School of Economics. The Jones-Klenow measurement is based on the socioeconomics of expected utility and incorporates estimates of GDP, consumption, inequality, leisure, and longevity.[142] The two main innovations we bring are an expansion of the Jones-Klenow approach and the explicit modeling of interactions between GDP drivers and components of welfare.[143] In particular, our welfare calculation takes into account the following additional components:

— The value of health over and above longevity, to reflect the fact that health has a separate utility beyond simply extra years of life. Indeed, some would argue that extending life for people with poor health or low incomes does little to increase welfare. In contrast, improvements in health at any age tend to be highly valued.[144] Given the increasing prominence of mental health, we also incorporate a negative component of technology-induced stress.

— A more nuanced approach to leisure, reflecting improved quality of leisure at home, resulting from home automation; increased voluntary leisure, which results from an opportunity to work fewer hours due to increased productivity and real wages; and forced leisure, resulting from unemployment, which is a negative contributor to well-being. The unemployed have been shown to gain less from leisure, because of the extra time they tend to spend on household work.

— Risk aversion to unemployment, reflecting the fact that the risk of unemployment, even if it does not materialize, hurts well-being, for example through increased stress, lower self-esteem, and additional precautionary savings, among other effects. At a societal level, rapid changes in unemployment have historically been associated with reduced levels of trust, as people often react negatively to such destabilizing circumstances.

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[141] For example, we have not included social connectedness in our model, given the lack of existing research on the channels and magnitude of technology's impact on it, even though most experts consider this to be an essential component of well-being. We also do not quantitatively model the impacts of technology scenarios on trust, and only implicitly include impacts of technology-led productivity growth on, for example, housing and environmental sustainability. See chapter 2 for more detail.

[142] Charles I. Jones and Peter E. Klenow, "Beyond GDP? Welfare across countries and time," *American Economic Review*, September 2016, Volume 106, Number 9.

[143] See chapter 2 and the technical appendix for a detailed discussion.

[144] Few explicit estimates compare the value of extra life years to the utility of enhanced health, and the estimates that do exist provide a varying range of values. Indeed, the concepts of longevity and health are not fully separable, because at some point, poor health leads to death. Nevertheless, it is not satisfactory to concentrate purely on longevity. For the purposes of our modeling, we have drawn on academic findings but also information implicit in, for example, well-being surveys, willingness-to-pay studies, and health authorities' methodologies for assessing the cost-effectiveness of different treatments.

— For consumption inequality, we take into account not just changes in wage levels and unemployment but also changes in the capital share of income, arising from the diffusion of technology. We also account for the differential wage dynamics for early versus late AI adopting firms.[145]

As shown in the literature, these additional components are all important for societal welfare. Moreover, they are all aspects of welfare that are influenced differentially by different paths of technology diffusion.

Extending our model from production, income, and expenditure (that is, GDP) to incorporate additional welfare components has several benefits. First, it gives us an indication of the relative importance of GDP in relation to additional components of welfare. Second, it allows us to understand the drivers that are likely to have the biggest impacts on welfare in different technology scenarios. Third, it provides detail on the sources of positive and negative effects, rather than just an aggregate picture. Technology affects people's lives through multiple channels, and understanding the contributions to the net effect is critical for prioritizing those Tech for Good tools that will be required to maximize positive, and mitigate negative, impacts.

To make comparisons to more traditional GDP estimates easier, we express the results as compound annual incremental growth rates in GDP and welfare from 2017 to 2030. To avoid any confusion about terminology, we refer to GDP (rather than income) when we mean total economic output and call the additional benefits over and above GDP "non-GDP welfare." (The sum of GDP and non-GDP welfare thus equals total welfare.)[146]

Finally, it is important to note that we do not claim that the model is exhaustive. Other components of welfare may play a role, and other feedback loops, while hard to quantify, may be significant. For example, risk of unemployment may lead to a reduction in consumption, better health can boost labor productivity, and so on. Moreover, our inequality measures are proxied by a variance approach that could be restrictive.[147] The model is thus illustrative. For all the caveats, however, the message that deploying a Tech for Good tool kit can reap positive benefits clearly emerges.

Scenarios of a technology-led future

Policy makers and businesses can take numerous stances in relation to technology diffusion and automation. These choices will largely determine the welfare outcomes of the future. To illustrate the magnitude and direction of different stances, we first establish an average scenario, against which alternative sets of choices are compared. This average scenario has been derived from MGI's previous research on the future of work and impact of AI, adjusted for friction in labor mobility and skills matching.[148] In this scenario, the incremental impact of technology raises GDP growth by 1.0 percent per year. The additional welfare growth beyond GDP is flat, as improved health and longevity is diminished by increased stress and counterbalanced by growing inequality.

Building on this average scenario, we deploy a set of assumptions to simulate the impact of different technology adoption paths. Our previous analysis shows that there are two particularly interesting axes along which policy makers' and businesses' prioritization

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

[146] No single established convention regarding nomenclature emerges from the literature. The word "income" is often used as a synonym for "GDP," which can cause confusion when also discussing household incomes and consumption.

[147] See, among others, Daniel Benjamin et al., "Beyond happiness and satisfaction: Toward well-being indices based on stated preference," *American Economic Review*, September 2014, Volume 104, Number 9; G. Charles-Cadogan, "Expected utility theory and inner and outer measures of loss aversion," *Journal of Mathematical Economics*, 2016, Volume 63, Number 1.

[148] *Jobs lost, jobs gained: Workforce transitions in a time of automation*, McKinsey Global Institute, December 2017; *Notes from the AI frontier: Modeling the impact of AI on the global economy*, McKinsey Global Institute, November 2018.

decisions make a crucial difference to welfare outcomes, so we have chosen these as the two dimensions on which to focus our scenarios (Exhibit 14).[149]

— **Focus of technology deployment.** At one extreme, businesses can choose to use technology mostly for cost reduction, production efficiency, automation, and labor substitution. Such a focus is most likely if governments limit the support for, or even resist, innovation-led technology adoption, including through restrictive regulation and lack of foundational legislation. At the other extreme, businesses can prioritize innovation-led technology adoption, focused on creating new products and markets, investing in human-centered complementary AI, and upgrading workforce skills. This stance is most likely if governments support and encourage R&D, boosting the return on investment from innovation. These choices will have a major influence on the degree to which job displacement is counterbalanced by the creation of new jobs. Our prior work on this issue has highlighted the importance of an all-encompassing digital "reinvention" approach for inclusive growth.[150]

— **Transition management.** This axis represents the degree to which the adoption of technology and the transitions it causes are proactively managed by both government and businesses. If there is little focus on retraining, labor mobility, and talent matching, or such efforts are not optimized by use of technology, the transition costs, negative externalities, and disruption risks increase. By contrast, active support to manage labor market transitions can smooth the path for both individuals and businesses. Not only will this reduce the amount of disruption and risk felt by workers, it will also enhance human capital and reduce skills gaps, further boosting productivity and growth. These choices together will likely determine the extent to which workers can learn new skills for the future and a flexible labor force can absorb some of the shocks of job dislocation. On this axis, we also include governments' stance on adoption of Tech for Good tools in public services, especially health. This will shape outcomes on the extent to which health and longevity receive a boost from technology implementation and can offset increases in inequality.

Government and businesses have many combinations of stances from which to choose. To ground our analysis in an internally consistent set of assumptions, we have focused on the four quadrants shown in Exhibit 14. Within each of these, there are more or less extreme scenarios. Below, we report on a range of realistic midpoint scenarios. The logic and assumptions for each scenario are further detailed in the technical appendix.

Our choice of scenarios is influenced by how different policy choices have already manifested themselves in different countries' current innovation, technology adoption, and welfare outcomes. Along the horizontal axis, governments play a key role in supporting research and development, and along the vertical axis, their procurement practices can spur technology adoption in public services. For example, significant public-sector investment in life sciences, including genomics, precision medicine, in silico modeling, and AI, have dramatically improved drug discovery and treatment options, including innovations such as cell therapy. The application of such leading-edge technologies, however, depends crucially on governments' ability to shape the regulatory environment, procurement, and incentive structures to ensure that healthcare providers can deploy medical advances in day-to-day patient care.

Governments also have it in their grasp to provide other supportive infrastructure, including the introduction of digital IDs and harmonized data exchanges. Best practices for this public-sector focus on driving innovation can be found in some Northern European countries, including Estonia, which has taken a lead in e-government and digital ID.[151] China is a significant

[149] As noted in chapter 2, analyzing the impact of a broad range of non-market interventions is outside the scope of this study. We have focused on a narrow set of levers that are most relevant in the context of technology transitions and the "what if" scenarios we have created for modeling their welfare impact.
[150] See *A winning operating model for digital strategy*, McKinsey & Company, January 2019; Jacques Bughin and Tanguy Catlin, "3 digital strategies for companies that have fallen behind," *Harvard Business Review*, February 12, 2019.
[151] Estonia is the first country in the world to offer 99 percent of all public services online 24/7, according to the e-Estonia guide, 2018, e-estonia.com.

funder of R&D in AI domains. Some US cities and regions, including Silicon Valley and Boston, meanwhile, have established strong ecosystems for AI startups, and a number of European cities, including Barcelona, Berlin, London, Paris, and Stockholm, are seeking to do likewise.

The business role is also decisive. Focusing technology adoption on innovation—the creation of new products and markets—increases total factor productivity and, through the dynamic of higher wages and higher-quality goods and services, spurs further demand. In other words, while there may be undesirable effects on how the economic pie is divided, the size of the pie increases. Typically, this additional demand more than outweighs the reduced labor requirements per unit of output. As they expand and benefit from technology adoption, companies will spread the gains through supply chains to smaller and midsize firms in their orbit.

However, even in an innovation-focused stance, the type of labor that is demanded will shift significantly. To realize the positive outcomes of the "Tech for better lives" quadrant, companies and governments will need to retrain much of the workforce to better equip it for the changing skills mix and business processes. As shown earlier, using technology to make worker retraining, talent matching, and labor mobility cheaper and more effective is likely to provide a

Exhibit 14

In our four scenarios, the focus of technology deployment and the approach to transition management determine the outcomes.

Source: McKinsey Global Institute analysis

major boost along with the well-being factors associated with job security and material living standards. But businesses will also need government to deploy a range of Tech for Good measures to counter challenges to inequality and unemployment risk.

The quadrant at the top right of the exhibit, "Tech for better lives," is the best outcome, in terms of both its hypothetical GDP gain and the potential boost to welfare. This scenario blends private and public cooperation for accelerating technology-based innovation in all domains, with a special focus on health, as well as AI and other technology that is complementary to human labor and seeks to augment rather than replace it. It simultaneously creates the conditions for purposeful retraining, better talent matching and more fluid labor markets, lowering unemployment risk, giving people more choices about the amount and quality of leisure they can enjoy, and boosting longevity and health. In other words, it makes concerted use of the Tech for Good tool kit.

As highlighted in Box 3 in chapter 2, we consider these scenarios market-based in the sense that businesses' and governments' actions are consistent with their economic incentives. For example, the scenarios assume retraining up to the point where it is optimal for both the workers and the companies that engage in the workforce. Additional public funding for frontier technology R&D and adoption is assumed to generate sufficient direct returns to justify the actions.

To fully close the gap between possible outcomes and a desirable future, bigger and bolder actions may be required that go beyond direct market incentives. An example of this is the launch of comprehensive and broad education programs by governments in the 1920s. The returns to such programs are not necessarily evident at first sight but emerge socially in the long term.[152]

Five initial results on welfare dynamics

To illustrate the welfare outcomes of the different stances, we contrast the results with the average starting-point scenario shown in the middle of Exhibit 15.

Five key insights emerge from this simulation. First, the potential impact of "Tech for better lives" on total welfare growth to 2030 is material, in the order of 1.5 to 2.0 percent per year and 45 to 95 percent higher than in the average scenario. Second, the growth in additional welfare, over and above GDP, is material: the upside to non-GDP welfare growth in "Tech for better lives" is around 0.3 to 0.5 percent per year, the same order of magnitude as the GDP growth upside of 0.3 to 0.5 percent. Third, improvements in health and longevity are the largest contributors to increased welfare. Fourth, the negative components of welfare are of a similar size in all scenarios—in other words, even though the mix of downsides changes, they do not disappear in lower-growth scenarios. Fifth, the downside risks to inequality are also present in the "Tech for better lives" scenario, indicating that nonmarket interventions may be required if these are to be reduced.

The total welfare gains from "Tech for better lives" are likely to be material
Moving from the average scenario in the center of the diagram in Exhibit 15 toward the top right-hand quadrant increases both GDP growth and non-GDP welfare growth. Together, these impacts add up to a significant upside potential of 0.5 to 1.0 percent incremental welfare growth per year compared to the average scenario. Even "pure" GDP growth increases by 0.3 to 0.5 percent annually. This is due to both higher productivity growth, following from a more innovation-focused investment in and adoption of technology, and lower unemployment, enabled by the public-private collaboration that leads to more fluid retraining and redeployment of workers. Moreover, the higher cumulative investment in human capital further boosts productivity growth, and all of these effects enable higher average wages and higher overall demand. The

[152] Some have argued that the move by Henry Ford to increase the minimum wage was an intervention beyond economic incentives provided by the market. A detailed economic review suggests, however, that Ford was not necessarily altruistic, but that his initiative was consistent with efficient wages: higher wages lead to less churn in the workforce and provide an incentive for workers to be more productive. See Daniel M. G. Raff and Lawrence H. Summers, "Did Henry Ford pay efficiency wages?," *Journal of Labor Economics*, October 1987, Volume 5, Number 4.

exact magnitude of these increases is of course uncertain, but these estimates are in line with previous sensitivity analysis conducted by MGI on the impact of AI on the global economy.[153]

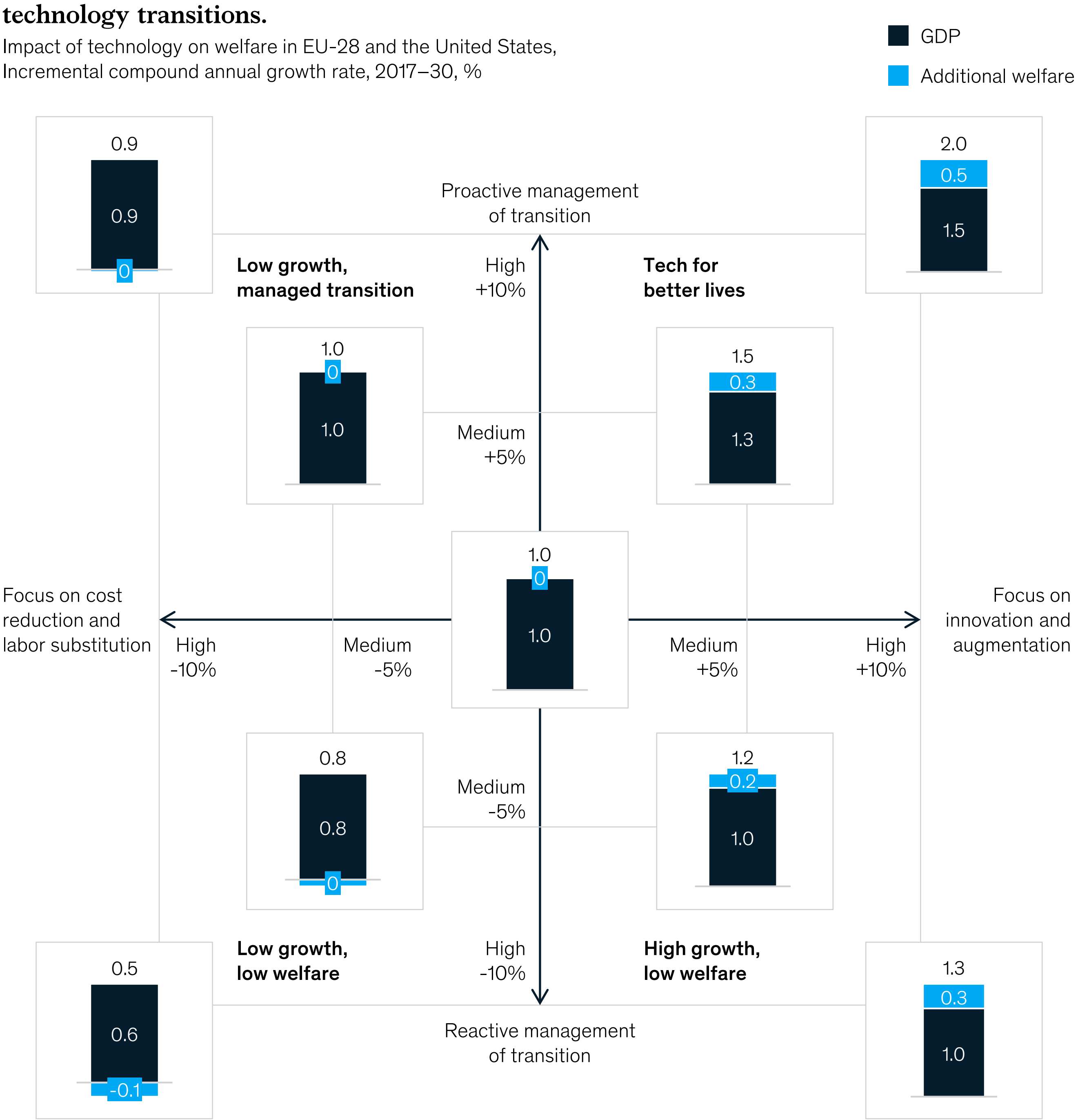
The additional welfare gains, over and above GDP, are also the most significant in the "Tech for better lives" scenario. Relative to the average scenario, welfare growth could be 0.3 to 0.5 percent higher annually. This is enabled by a combination of higher quantity and quality of leisure, and significantly enhanced health and longevity (discussed in more detail below). With higher wages, and in line with historical trends, more workers can afford to reduce the hours

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

Exhibit 15

Welfare is increased through growth-focused and proactive management of technology transitions.

Impact of technology on welfare in EU-28 and the United States,
Incremental compound annual growth rate, 2017–30, %



Note: Additional welfare and GDP CAGRs are not additive, and their sum does not equate exactly to the welfare CAGR.
Source: McKinsey Global Institute analysis

they work and enjoy more leisure time. Technological innovations, such as home automation and new appealing forms of entertainment, will enhance the quality of this leisure time. And lower unemployment means that a smaller proportion of people suffer from “forced leisure,” the utility of which is significantly lower than that of voluntary leisure, not least because of the stress and well-being reductions associated with unemployment.

The additional welfare effects, over and above GDP, are important

In our simulation, GDP growth is the largest component of total welfare growth. This is consistent with Jones-Klenow estimates: non-GDP welfare growth for Western European countries in their analysis over the period 1980 to 2007 was around 50 percent of underlying GDP growth.[154] However, when we contrast these estimates to the average scenario, it is clear that incremental non-GDP welfare growth is of the same order of magnitude as the incremental GDP growth in the “Tech for better lives” scenario. The upside to non-GDP welfare growth is around 0.3 to 0.5 percent per year, the same as the upside to GDP growth.

This is not surprising, given the significant value individuals and societies put on the factors modeled as part of non-GDP welfare. Even traditional welfare calculations have long recognized that life expectancy, leisure time, and inequality are all important considerations.[155] Research has shown that labor productivity growth over time is correlated with an overall reduction of hours worked, giving people more choice over how they spend their time. Likewise, increasingly smart homes may reduce household work and therefore enhance the genuine amount of time people can dedicate to leisure.[156]

Even the quality of leisure matters: based on analysis of the British Household Panel Survey from 1996 to 2009 covering more than 100,000 households, for every additional unit of “Satisfaction with use of leisure,” self-reported life satisfaction increased by a factor of 0.17, in a multivariate model with an R-squared of 0.74. In contrast, a unit of income was worth only 0.11 and a unit of extra leisure time (independent of its quality) 0.07.[157]

These findings highlight the importance of looking beyond GDP when assessing the impact of technology on future well-being.

Improvements in health and longevity could be the largest contributors to increased welfare beyond GDP

By simulating welfare via its multiple components, we also gain insights into the relative contributions of different drivers to future welfare growth. Beyond GDP, by far the largest impact in our simulation comes from improved longevity and health. Longevity contributes 0.5 to 0.6 percent to welfare growth and health an additional 0.3 to 0.5 percent in the “Tech for better lives” scenario. Indeed, the positive gains in longevity and health outweigh the negative effects on inequality in this scenario.

Before turning to the health and longevity results themselves, it is worth pausing to understand why consumption inequality rises in the “Tech for better lives” scenario. This is the net result of two opposing forces. As in the “High growth, low welfare” scenario, the rapid diffusion and adoption of technology, though biased toward product and market innovation, still creates significant changes in the workforce. As our research on the future of work and

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[154] Charles I. Jones and Peter J. Klenow, “Beyond GDP? Welfare across countries and time,” *American Economic Review*, September 2016, Volume 106, Number 9.

[155] Mark Aguiar and Erik Hurst, “Measuring trends in leisure: The allocation of time over five decades,” *Quarterly Journal of Economics*, August 2007; Valerie R. Ramey and Neville Francis, “A century of work and leisure,” *American Economic Journal,* Volume 1, Number 2, July 2009.

[156] According to some estimates, the time spent on household chores fell from 58 hours per week in 1900 to 18 in 1970 and less than eight hours in 2015. See Max Roser, “Working Hours,” 2019, OurWorldInData.org.

[157] Richard Layard, *Measuring wellbeing and cost-effectiveness analysis: Using subjective wellbeing*, discussion paper number 1, Centre for Economic Performance, December 2016.

skill shifts has shown, a very significant proportion of people will need to be retrained to realize these high-technology, high-growth scenarios.[158]

As with all technology-led revolutions, a larger proportion of the benefits of productivity and new demand is likely to accrue to owners of capital rather than to labor, at least in the short term and in the absence of policy changes. Because those owners are typically in the top quintile of the income distribution, the increased capital income exacerbates income differentials. Previous findings of MGI research into the resilience of European countries' inclusive growth model and their social contracts suggest that technology may be the single largest contributor to the increase of income inequality.[159]

While the "Tech for better lives" scenario does reduce the element of inequality that is driven by wage differentials, our simulation suggests that this is likely to be outweighed by the shifts in the share of income accruing to capital versus labor. This further reinforces the importance of modeling welfare at the level of individual drivers rather than aggregates, to tease apart the positive and negative effects from the overall net effect.

As mentioned, the negative effects on consumption inequality are outweighed by a significant boost to welfare from improved healthy life expectancy. This is expected: previous analyses of the value of health and longevity indicate their critical role in life satisfaction. The balance of academic literature on the utility of life and health seems to suggest that this has historically been undervalued. For example, while health authorities in the United Kingdom and other Western economies typically value a quality adjusted life year at around $50,000, some academics have recently argued that a more appropriate valuation might be around $200,000.[160]

To put this in perspective, Kevin M. Murphy and Robert H. Topel estimated that the additional welfare derived from longevity in the United States in the period 1970 to 2000 was about half of the average GDP growth over the period.[161] In other words, welfare growth was boosted by 50 percent by including the life expectancy component, with resulting total welfare growth at 150 percent of GDP growth. Murphy and Topel suggest that the utility of health, over and above longevity, may be even more valuable. Other estimates are in a similar order of magnitude. For example, the Jones-Klenow analysis suggests that increases in life expectancy in Western Europe between 1980 and 2007 added 56 percent of welfare on top of GDP growth, and the IMF suggests that for Western European countries between 2007 and 2014, the longevity component added 125 percent on top of GDP growth.[162]

Granted, other estimates put the relative value of life and health in a much lower range. For example, Kerry Hickson estimates that improvements in longevity and health contributed about an additional 0.3 to 0.4 percent of welfare growth per year in England from 1900 to 2000. Given an annual average GDP growth rate of approximately 1.8 percent, this amounted to an uplift of about 20 percent on top of GDP growth.[163] Hickson also suggests that the bulk of the additional welfare came from increased longevity rather than improved health, especially over longer time frames. William Nordhaus, reporting on work by David Cutler and

[158] *Jobs lost, jobs gained: Workforce transitions in a time of automation*, McKinsey Global Institute, December 2017; *Skill shift: Automation and the workforce*, McKinsey Global Institute, May 2018.
[159] *Testing the resilience of Europe's inclusive growth model*, McKinsey Global Institute, November 2018.
[160] See, for example, Beth Woods et al., "Country-level cost-effectiveness thresholds: Initial estimates and the need for further research," *Value Health*, December 2016, Volume 19, Number 8; *Valuation of a life*, Social Value UK, June 9, 2016; Merena Nanavaty et al., "The use of incremental cost-effectiveness ratio thresholds in health technology assessment decisions," *Journal of Clinical Pathways*, Volume 1, 2015.
[161] Kevin M. Murphy and Robert H. Topel, "The value of health and longevity," *Journal of Political Economy*, 2006, Volume 114, Issue 5.
[162] Charles I. Jones and Peter E. Klenow, "Beyond GDP? Welfare across countries and time," *American Economic Review*, September 2016, Volume 106, Number 9; Geoffrey J. Bannister and Alexandros Mourmouras, *Welfare vs. income convergence and environmental externalities*, International Monetary Fund working paper number 17/271, November 2017.
[163] Kerry Hickson, "The GDP value of twentieth-century health; Improvements in developed economies: Initial estimates for England," *Review of Income and Wealth*, June 2014, Series 60, Number 2.

Elizabeth Richardson, estimates the extra value of health, over and above longevity, at 1 to 15 percent of the welfare gains from extra years of life.[164]

Nevertheless, health matters. In the World Happiness Survey, healthy life expectancy is one of the six key variables that contribute to explaining countries' happiness scores from 2005 to 2018.[165] In the United Kingdom, the Office for National Statistics in 2013 performed a comprehensive analysis of factors that predict individuals' well-being, with health emerging as the most important factor. In Richard Layard's work, for an individual 34 years of age, more than 50 percent of life satisfaction is attributable to the combination of physical and mental health.[166] As described in chapter 3, innovations in medical and healthcare technology, combined with an enabling regulatory environment, significant R&D support, progressive procurement practices, and deployment of new technology in public healthcare, have the potential to boost both health status and length of life for individuals.

The downside components to welfare and inequality are present in all scenarios
To fully understand the implications of the different stances, we need to look separately at the welfare components with positive and negative effects, and how they vary across the scenarios. While there can be significant boosts to welfare via income and health and longevity, this should not be used to mask the negative factors such as wage inequality, inequality from a changing capital/labor share, changes to consumption from unemployment, and the negative effects of risk of unemployment. Moreover, the mix of drivers that can cause negative welfare effects is not uniform across scenarios. Exhibit 16 shows estimates of the technology-driven welfare growth in 2017 to 2030 in comparison with previous periods, 1980–2007 and 2007–14 (see Box 5, "How future technology-driven welfare growth might compare to the recent past").

[164] William D. Nordhaus, *The health of nations: The contribution of improved health to living standards*, NBER working paper number 8818, March 2002; David Cutler and Elizabeth Richardson, "Measuring the health of the U.S. population," *Brookings Papers: Microeconomics*, 1997.
[165] The other five are: GDP per capita, social support, freedom, generosity, and absence of corruption. See John F. Helliwell, Haifang Huang, and Shun Wang, "Changing World Happiness," in *World Happiness Report 2019*, 2019.
[166] Richard Layard, *Measuring wellbeing and cost-effectiveness analysis. Using subjective wellbeing*, discussion paper number 1, Centre for Economic Performance, December 2016.

Box 5
How future technology-driven welfare growth might compare to the recent past

To interpret the results of our modeling, and put them into context, it is useful to compare them to historical trends. However, existing estimates of historical welfare growth do not typically separate out the impact of technology from other factors. In order to allow a like-for-like comparison, we used historical welfare calculations as well as the broader literature on the impact of technology on GDP and the other welfare components to construct an estimate of the technology-driven historical welfare growth, shown in Exhibit 16.

This analysis suggests three insights that highlight the importance of further research on the topic. First, even during the financial crisis and its aftermath, technology contributed positively to welfare growth. This was despite weakness in GDP growth; and thanks to continued technology-enabled improvements in health and longevity.

Second, our average scenario projection for welfare growth to 2030 is slightly below historical growth in the period from 1980 to 2007—the most recent era characterized by wide-spread ICT diffusion. The somewhat slower future outlook in our average scenario is largely due to the drags on welfare growth from anticipated risks associated with labor market transitions.

Third, not achieving the "Tech for better lives" scenario could expose the economy and society to levels of downside similar to the financial crisis and much higher than those experienced in the 1980 to 2007 period. In terms of forward-looking scenarios, it is only in the "Tech for better lives" scenario that the negative welfare components get close to the lower long-run average of 15 percent of gross welfare growth.

In our average scenario, the downside factors represent a welfare loss of minus 0.6 percent annually. These losses are linked to the same factors that also drive positive welfare gains through productivity growth. Therefore, the net welfare growth of 1.0 percent in this scenario is comprised of a positive 1.0 percent from GDP growth, 0.6 percent of additional welfare from longevity, health (net of stress) and leisure, and a negative effect of 0.6 percent from the downside factors.

While the gains from technology diffusion vary significantly between the different scenarios, the absolute magnitudes of the negative effects stay the same. Resisting technology diffusion is therefore likely to be worse than embracing it. Not only does the "Low growth, low welfare" scenario generate less upside, it generates the same downside as other scenarios. This means that, on a "risk/return" basis, it is worse. The combined negative welfare components in the "Low growth, low welfare" scenario deduct around 47 to 53 percent from the gross welfare gain; whereas in "Tech for better lives," they only reduce gross welfare by around 27 to 32 percent.

Exhibit 16

Outcomes of the technology-driven welfare growth simulation in 2017–30.

Compound annual growth rate, %

	Historical welfare growth driven by ICT, weighted by population		Projection of welfare growth driven by ICT, 2017–30			
	1980–2007	2007–14	Average	Low growth, low welfare	High growth, low welfare	Tech for better lives
Total net welfare growth	1.1	0.8	1	0.5–0.8	1.2–1.3	1.5–2.0
GDP growth	0.7	0.4	1	0.6–0.8	1	1.3–1.5
Longevity	0.3	0.3	0.4	0.3	0.5	0.5–0.6
Health	0.2	0.2	0.2	0.1–0.2	0.3	0.3–0.5
Stress	n/a	n/a	-0.1	-0.1	-0.2	-0.2
Consumption inequality	-0.1	-0.2	-0.3	-0.3	-0.3	-0.3
• Wage inequality	-0.1	-0.1	-0.2	-0.2	-0.2	-0.2
• Capital/labor inequality	0	-0.1	-0.1	-0.1–0	-0.1	-0.1
Consumption as a share of income	0	0	-0.1	-0.1	-0.1	0
Aversion to the risk of unemployment	n/a	n/a	-0.2	-0.2–-0.1	-0.2–-0.1	-0.2–-0.1
Leisure	0	0.1	0.1	0.1	0.1	0.1
Negative components as a share of total gross welfare growth, like-for-like comparison[1]	15.4	33.3	26.3	32.7–36.1	23.1–24.3	15.1–19.5
Negative components as a share of total gross welfare growth, total			41.4	46.8–52.9	35.0–37.8	26.7–32.2

[1] Calculated like-for-like, ie, in the simulated scenarios. Aversion to the risk of unemployment and stress are not included in the calculation.

Source: McKinsey Global Institute analysis

The nature of the mix of downside risks also changes in the different scenarios. In the "Low growth, low welfare" scenario, the downside risks, which also contribute to inequality, manifest themselves as lower wage growth and higher unemployment. This is because a focus on cost reduction and labor saving through automation reduces the potential of technology to boost demand and creates more skill-biased wage dispersion and worker displacement in the short term. In contrast, in the "Tech for better lives" scenario, the negative inequality effects are more concentrated around higher wage inequality and an increase in the income share of capital versus labor. The "Low growth, low welfare" scenario therefore brings more risk of absolute poverty whereas the "Tech for better lives" scenario's downsides manifest more as a relative equality issue.

It is also important to consider the difference in the nature of inequality between the two high-innovation scenarios: "High growth, low welfare" and "Tech for better lives." In the time horizon between 2017 and 2030 we see little difference both in wage and capital/labor inequality growth (the difference is below 0.1 percent per year). However, in the longer term, as discussed in a prior MGI report on the resilience of European inclusive growth, inequality can be expected to decline in the "Tech for better lives" scenario.[167] The reason for this is the higher level of technology diffusion in this scenario, which, in the short term, leads to more skill inequality and a divide between "winners" and "losers," but in the longer term, beyond peak diffusion, will temper inequality growth as matching of skills stabilizes at the new level.

Our simulation shows that innovation-led growth through technology adoption brings higher welfare potential in the form of GDP growth and longevity and health gains, but also downsides in the form of inequality. Careful management of the technology transition thus becomes critical to capturing the upside benefits while mitigating the downside risks.

Other, bolder moves may be required

These results indicate that technology diffusion in the near future is likely to leave some inequality. Even in the "Tech for better lives" scenario, inequalities and downside risks persist. Market-based technology diffusion on its own, even with some supportive government action, is unlikely to solve all the problems that arise.

It is promising that the positive welfare gains in the "Tech for better lives" scenario may be large enough to finance significant nonmarket intervention. The significant productivity increases in this scenario are important to meet people's expectations of rising living standards, especially in light of growth challenges facing some developed economies, such as an aging population. In the "Low growth, low welfare" scenario, there may be less room for maneuver—and a similar magnitude of downside risks. Governments therefore have a critical task in articulating the desirable state of society in the future and identifying the market and nonmarket levers necessary to achieve it.[168]

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

5. Obstacles, challenges, and implications for stakeholders

The analysis above illustrates the size of the prize: a 45 to 95 percent boost to annual welfare growth over the next decade or so compared to the average scenario. It also indicates that even the best-case scenario involves negative effects and downside risks. Moreover, significant obstacles stand in the way of the "Tech for better lives" scenario becoming a reality. To overcome these obstacles and mitigate the risks will require concerted action by stakeholders—which in itself could be a significant obstacle.

Three major obstacles: access, implementation, and technological risks

While multiple examples exist of positive change that technology can bring in the areas of societal well-being, promising use cases struggle to be deployed at scale. For example, augmentation of teaching with technology shows good results, with exciting implementations of adaptive learning, AI-powered teacher assistants, and immersive learning experiences. However, it is still far from common practice in schools and at-work education. Indeed, while education technology investment grew at a fast pace to total almost $17 billion in 2018, it represented a mere 0.3 percent of the estimated global education sector.[169]

Among obstacles to scalability, three are the most prominent. First is the lack of sufficient infrastructure and access to the digital economy for all. For example, many schools in rural areas, which would benefit the most from technological augmentation, do not have adequate broadband connections. Second is the high level of required investment and high complexity of implementation. Finally, technology itself comes with new risks, such as data violation and cyberfraud, that require mitigation in the form of new approaches, regulation, and cultural norms.

Infrastructure and access to the digital economy

Access to digital networks remains uneven around the world and within countries. More than half of the world's population currently has access to the internet, but that still leaves about 3.6 billion people who are not connected.[170] A large proportion of them are located in less than two dozen countries, primarily in Africa, but gaps exist in all countries.[171] Even where connections are available, some people cannot afford coverage. The cost can differ significantly: in the United States, for example, the median price for connectivity in rural areas is higher than in urban or suburban areas, while rural users are lower earners and service quality is often lower. This results in broadband use rates varying from about 62 percent in rural counties with lower median income to 80 percent in urban counties with higher median income.[172]

[169] See, for example, Ashmeet Singh, "Understanding the EdTech product landscape," Medium, April 19, 2018; "Global report predicts EdTech spend to reach $252bn by 2020," *Finance Digest*, May 28, 2016; and Valerie Strauss, "Global education market reaches $4.4 trillion—and is growing," *Washington Post*, February 9, 2013.

[170] The International Telecommunication Union estimates that 51.2 percent of the world population, currently 7.7 billion, had access to the internet as of 2018, itu.int/en/ITU-D/Statistics/Pages/stat/default.aspx. Internet World Stats cites a higher penetration rate of 56.3 percent, as of March 2019, internetworldstats.com/stats.htm.

[171] Africa has the lowest penetration rates, at 24 to 36 percent, but they are growing. Asia's penetration rate is reaching 50 percent. North America and Europe have rates of 80 percent or higher. See ITU and Internet World Stats estimates.

[172] See Phillip Dampler, "Census Bureau reports internet penetration lowest in urban poor and rural areas," Stop the Cap!, December 10, 2018: Sharon Strover, "Reaching rural America with broadband internet service," The Conversation, January 16, 2018; and Monica Anderson, "About a quarter of rural Americans say access to high-speed internet is a major problem," Pew Research Center Fact Tank, September 10, 2018.

For artificial intelligence, the availability of large quantities of data is also a prerequisite. For now, much data are either not collected and structured systematically or hard to access. This could be because companies collecting information aim to monetize the data, or because the data themselves are sensitive, such as personal health records.[173]

Digital literacy is another aspect of the access challenges. Even those who do have access to the internet are not universally equipped to benefit from the information and tools available. While quantifications of digital literacy and illiteracy are scarce and infrequent (available analyses generally rely on the OECD's PIAAC assessment dating from 2012), the notion of a digital divide has become increasingly prevalent. It points to the challenges faced by older or less educated parts of the population.[174]

Implementation challenges

The cost and complexity of implementing Tech for Good tools are major potential obstacles that will need to be overcome. Finding the requisite skills and managing the needed data are among the most challenging.

Even established digital technologies have yet to become fully mainstream across entire economies: on average, industries globally are less than 40 percent digitized.[175] Digital transformation programs require a fundamental reimagination and reorientation of company strategy and workplace practices. This in turn requires skilled employees who can help with the transition—and a new mindset among corporate leaders. In one survey from 2018, 65 percent of chief information officers say they are facing hiring challenges.[176] Moreover, churn rates among digital business professionals can be high.

Even if companies use these technologies to develop and support new business models, and if the adoption of the technologies advances, their integration into business processes has proven to be complex. MGI has quantified the pace of digital adoption and absorption into organizational practices in the United States, Europe, and China, and found that all three economies are still far from the digital frontier. On average, they stand at only around 20 percent of the total potential.[177]

Setting up large-scale retraining to equip workers with the skills they will need and make them more mobile in the labor market will require changes to the way skills are delivered, including software to reduce the cost and improve access to retraining, among other organizational changes. It will allow adaptive learning programs to be created and updated regularly, flexible enough to allow for different types of skills, combined with information about market needs for skills. A certification mechanism to ensure that reskilling is recognized across companies and across sectors will also be needed. This can only be achieved through close coordination between business and the public sector.

AI could become a source of competitive advantage. However, its implementation is far from trivial. The challenge includes the difficulty of obtaining data sets that are sufficiently large and comprehensive to be used for training, labeling the training data, and explaining in human terms the results from large and complex models. Furthermore, AI models continue to have difficulties in carrying their experiences from one set of circumstances to another. That means companies must commit resources to train new models even for use cases that are similar to previous ones.[178]

[173] For a discussion of data accessibility, see *Notes from the AI frontier: Applying AI for social good*, McKinsey Global Institute, October 2018.
[174] For an example of quantification, see "A description of U.S. adults who are not digitally literate," American Institutes for Research, May 2018, indicating that 16 percent of adults in the United States are digitally illiterate, based on 2012 data. For analyses of the digital divide, see, for example, the OECD's "Bridging the Digital Divide" initiative and "Exploring the UK's digital divide," Office for National Statistics, March 2019.
[175] Jacques Bughin, Laura LaBerge, and Anette Mellbye, "The case for digital reinvention," *McKinsey Quarterly*, February 2017.
[176] *CIO survey 2018: The transformational CIO*, Harvey Nash/KPMG.
[177] *Digital Europe: Realizing the continent's potential*, McKinsey Global Institute, June 2016.
[178] Michael Chui, James Manyika, and Mehdi Miremadi, "What AI can and can't yet do for your business," *McKinsey Quarterly*, January 2018.

Costs of data and storage have declined sharply in recent years, but some of the technologies we outlined in the chapter on use cases require high-cost hardware, software, or both. Virtual reality is one example. Some companies are starting to use augmented reality tools in manufacturing. Training programs are being developed on a tailored basis, either for assembly and maintenance tasks or, in the aviation industry, even for pilot training.[179] However, the costs of such technologies for now are out of the reach of some sectors that could benefit, such as construction workers who could use VR to work more productively.

Technology-related risks and limitations
Reliance on technology comes with benefits but also bears new risks. The radical nature of the ongoing technology transition necessarily implies that the risks are not just an extension of the previous challenges but require fundamental changes to core aspects of our society, including how we think about our identity, security, and rights. Concerns about technology are justified by recent events, such as security breaches in prominent companies, data theft, and information misuse.

AI provides even more powerful examples of potential risks. Its full potential can by definition be harnessed only if we fully rely on it for decision making, giving it free rein in processing data beyond our human ability to cross-check and verify. As discussed in chapter 1, this requires a high level of trust and opens questions about "explainability," accountability, ethics, and bias that are widely debated.

In some areas, society has grown disillusioned with technologies that were once in vogue. Social networks, long considered a new medium for users to connect, create and share new content, and shape the internet, are now sometimes perceived as a source of social anxiety, data misuse, and unchecked spread of violence and fake news.

For these risks to be mitigated they must be well understood and then proactively managed. This will require joint efforts by all stakeholders, including tech companies, large and small businesses, researchers, policy makers, and society itself, as it can be done only with a combination of technological solutions, regulation, vigilant observation of outcomes, and inclusive debates.

Governments and individuals can help overcome barriers and scale the use of Tech for Good tools

The risks and obstacles noted above are not insuperable. All stakeholders have roles to play in overcoming them and scaling the use of technology in a way that smooths transitions and leads to better outcomes. Businesses have a particular opportunity to do so, since their actions have direct effects on individuals as employees and consumers, as we discuss in the next section. Government and civil society more broadly also can and will need to contribute to ensure that Tech for Good tools are widely deployed for the benefit of all.

Government action is a key for managing technology transitions and encouraging innovation
Governments can be instrumental in ensuring that technology transitions are well managed and in encouraging innovative development and use of technologies. They have a direct role to play in addressing the obstacles noted above. We have not modeled the types of policy interventions that will be necessary to address issues such as rising inequality and achieve the best outcomes from our scenarios, but our work does prompt some questions that will require further research (see Box 6, "Policy questions and challenges from the Tech for Good tool kit").

[179] See Daniel Dixon, "How brands like Boeing use augmented reality in production," Medium, August 29, 2018; Alan Boyle, "Boeing foresees a doubling in demand for pilots by 2037, and works on ways to fill it," *Geekwire*, July 23, 2018.

— For access to infrastructure, governments can make a significant difference in a formal way, through policies and investment aimed at improving infrastructure coverage and quality, for example with broadband rollout and public Wi-Fi. They also have power to influence outcomes through legal frameworks and by setting standards. For example, regulation and standards for data collection and usage will create greater transparency and certainty for all stakeholders, especially in regard to sensitive issues such as the types of data that can be collected, stored, and shared, and under what conditions.

— Digital inclusion is also a core area for government involvement, ensuring that vulnerable groups gain access not just to the internet but also to a panoply of digital services. As noted, education is a key enabler for technology adoption and management of transitions, including but not limited to STEM subjects. Governments play a direct role in influencing curricula and could renew emphasis on ICT skills and digital literacy, for example, but also work to develop curricula to include the social and emotional skills and higher cognitive abilities that machines have a hard time replicating. Digital ID programs can be a powerful tool for connecting citizens with public services and nudging digital adoption, and a growing number of governments are rolling out such initiatives.[180]

— In implementation, governments can use public spending to reduce innovation costs for business and set the direction of technology development through procurement and open markets. Government R&D is already being used effectively in some countries including Estonia, alongside China and the United States, to ensure that frontier technologies are developed and embraced (Exhibit 17). Perhaps the most powerful boost that government can give to frontier technologies comes from the public sector itself. Adopting technologies in government activities will improve the quality and efficiency of public services and hasten broader diffusion in society.

[180] *Digital identification: A key to inclusive growth*, McKinsey Global Institute, April 2019.

Box 6

Policy questions and challenges from the Tech for Good tool kit

In our modeling, we considered only a narrow set of policy choices. However, achieving the best outcomes from our scenarios will likely require policy action and may call for larger-scale intervention. Restoring trust in institutions and political leadership will be essential; research shows that lack of trust is linked to fear of unemployment and inequality.[1] It is beyond the scope of this research to identify a full list of interventions and appropriate pathways, but we do identify some key questions that will require further research. They include:

— Can public R&D spending be harnessed to accelerate innovation and support market expansion? And if so, where should it be directed?

— How can public administrations achieve the same level of technological transformation and adoption efficiency and efficacy as businesses?

— What kind of government and business intervention can deliver needed skills—most importantly, digital and cognitive skills—to large parts of the population? How do spending and incentives, as well as skills system design, need to change?

— What kinds of incentives can help secure new types of employment, raise entrepreneurship, and reduce risks of innovation for a wider range of firms?

— And finally, given the likelihood that labor saving gains during the transition period will take place faster than new growth from innovation can be felt, how can government and businesses ease interim technological unemployment and overcome wage stagnation?

[1] See Johan Graafland and Bjorn Lous, "Income inequality, life satisfaction, inequality and trust: A cross-country panel analysis," *Journal of Happiness Studies*, 2018.

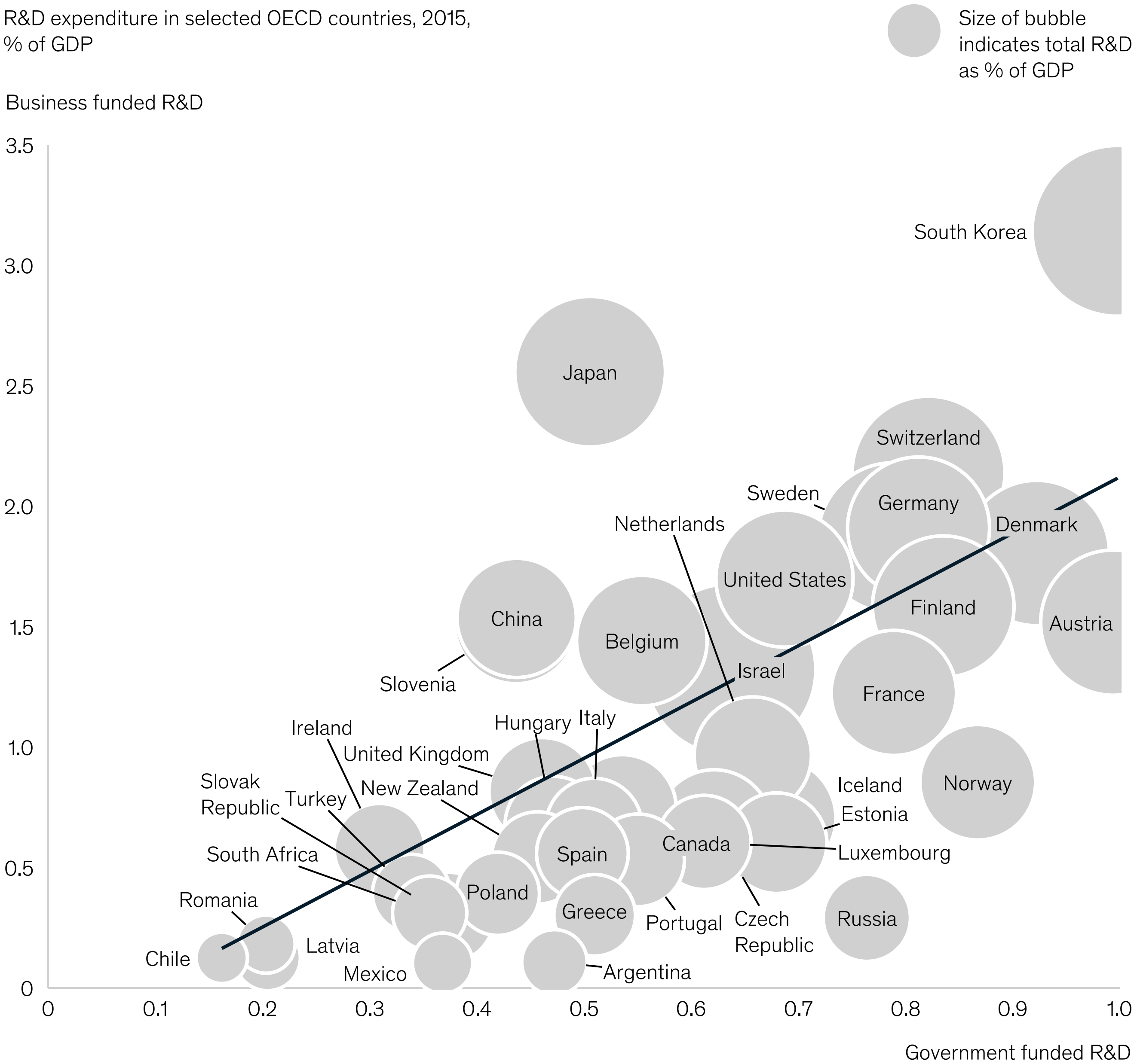
— Finally, governments have a relatively new, and essential, role to play in proactive management of data usage. Open data initiatives can create a broad-based culture of data sharing that will underpin business and other usage of AI technologies. At the same time, the state appears as a critical regulator of data rights and usage, aiming to defend the privacy of personal information as it supports the transparency and accuracy of public information, including data related to the private sector's social responsibility practices.[181] Regulation that encourages data sharing but maintains privacy of personal information, for example, will build confidence in the system and accelerate diffusion.[182]

[181] For a discussion of the need to enhance the quality of information on companies' sustainability practices, see Xiaomeng Guo, Guang Xiao, and Fuqiang Zhang, *Effect of consumer awareness on corporate social responsibility under asymmetric information*, Olin Business School, Washington University in St. Louis, September 2017.
[182] *The age of analytics: Competing in a data-driven world*, McKinsey Global Institute, December 2017.

Exhibit 17

Government funding and business financing of R&D are complementary.

R&D expenditure in selected OECD countries, 2015, % of GDP



Source: OECD; McKinsey Global Institute analysis

Civil society and individuals have an important role to play in focusing attention on the well-being aspects of technology adoption

While government and business play central roles in ensuring the welfare-oriented adoption and diffusion of frontier technologies, individuals and civil society more broadly are not bystanders. They can contribute to the overall focus on proactive management of technology in several ways, including the following:

— Helping build a Tech for Good ecosystem. Contributing to data collection initiatives, including through open-data platforms, and joining crowdsourcing initiatives is a constructive way to help steer the direction of tech adoption. People can help make technology adoption more inclusive by feeding sites such as Wikipedia with their own knowledge and cultural capital, sharing best practices, and flagging abuses. Given the continuing gaps in online usage, even in advanced economies, a constructive role exists for many of those well versed in digital technology to help peers with less developed digital skills, including the elderly.

— Public pressure can help drive government and business action. Pressure groups as well as individuals who use social media and other outlets to call for change can become unstoppable forces. Insisting that new technologies are deployed for the betterment of well-being and pushing to eradicate negative outcomes can become crucial elements in scaling the use of Tech for Good tools. The calls for action can be effective at a societal level as well as at a corporate level, through shareholder activism, among other approaches. For example, the standards set forth by the Financial Stability Board's Task Force on Climate-related Financial Disclosures in June 2017 have garnered rapid momentum. Over 580 large corporations, including financial firms with about $100 trillion in assets under management, expressed their support as of February 2019, thereby committing to improved risk disclosure, which in turn should lead to a more efficient allocation of capital from an overall welfare point of view.[183] In this reporting process, corporations may lead the way, in comparison to smaller businesses for which the processes and cost of disclosure may prove more challenging—although examples of socially responsible practices by small and medium-size enterprises abound.[184]

— Consumer power can help validate or invalidate technologies that have been proven to be intentionally addictive, harmful, or unethical. Some precedents for this already exist, such as the Algorithmic Justice League created by an MIT student, Joy Buolamwini. This is a citizen-led initiative committed to raising awareness and allowing individuals to contribute to testing software, including facial recognition applications, to help companies accumulate more inclusive data points. Companies can submit a request for the league to help identify bias, and individuals can directly report applications where they experienced bias and collectively reach out to the stakeholders. The initial focus was on facial recognition, but the founders are widening the scope.[185] One dating website recently gave a public explanation of the methods it used for matching and said it was downplaying its previous use of a scoring system that had proven controversial.[186]

For companies, the opportunity is to prioritize tools that are good for business and society

Companies will drive the large-scale workforce transitions that are likely to accompany the implementation of these technologies in the workplace. They will also help determine material living standards through greater efficiency and better products and services at affordable prices. At the same time, as we have seen in our modeling, business stands to benefit if the

[183] See the task force's website for the full list of supporters: fsb-tcfd.org/tcfd-supporters/; and Nina Chestney, "Climate-related financial disclosure becoming more mainstream: G20 task force," Reuters, September 26, 2018.

[184] For more information about the challenges and opportunities faced by SMEs, see Dimosthenis T. Mousiolis et al., "Corporate social responsibility in SMEs and MNEs: The different strategic decision making," *Procedia*, February 2015; Mark Hillsdon, *The impact of the Task Force on Climate-related Financial Disclosures*, Ethical Corporation, August 6, 2018; and Bridget Weston Pollack, *Corporate social responsibility: What your small business needs to know*, US Small Business Administration, July 6, 2017.

[185] Joy Buolamwini, "Unmasking bias," Medium, December 15, 2016.

[186] *Powering Tinder—the method behind our matching*, Tinder, March 15, 2019.

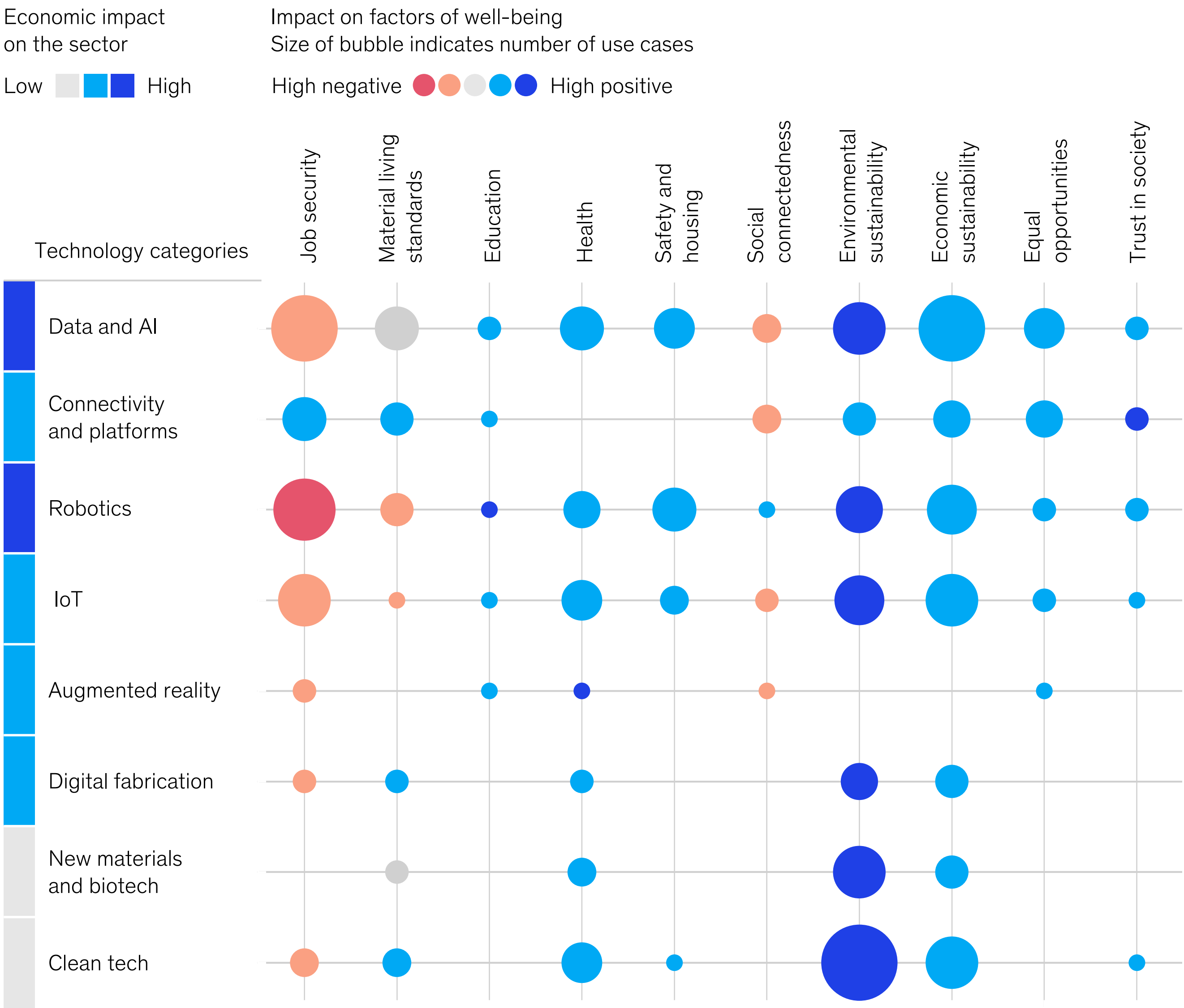
transitions are smooth and has much to gain—or lose—by ensuring not only that technology becomes a tool for innovation but also that its adoption is carefully managed.

To capture the benefits of technological adoption, companies will need to embrace Tech for Good tools, both the innovation aspects and the focus on proactive management of transitions. Retraining workers will enable them to fill a growing skills gap. Accelerating product innovation will open new markets and create new jobs. Higher job satisfaction and safety will improve profitability. And addressing societal issues head on will improve the trust and stability needed for sustainable consumption and economic growth that will ultimately benefit business, too.

Exhibit 18

A large proportion of the use cases that create value for businesses also have a positive impact on many well-being factors.

Manufacturing example



Note: Estimated economic impact based on expert calls, previous MGI reports, and press research. Size and colors of bubbles based on McKinsey Global Institute proprietary use cases library (~600 use cases in May 2019).

Source: McKinsey Global Institute analysis

Some technology applications are good for business and for welfare

Our library of use cases points to a wide range of applications that are good for well-being, improve innovation, or mitigate some transition effects—and sometimes all three. This research has not attempted to undertake an exhaustive analysis of the economy to identify the overall impact on welfare. However, we looked more closely at two sectors, retail and manufacturing—which together are responsible for about 30 percent of employment and deliver up to 39 percent of gross value added in Europe—and mapped our use cases to them.[187]

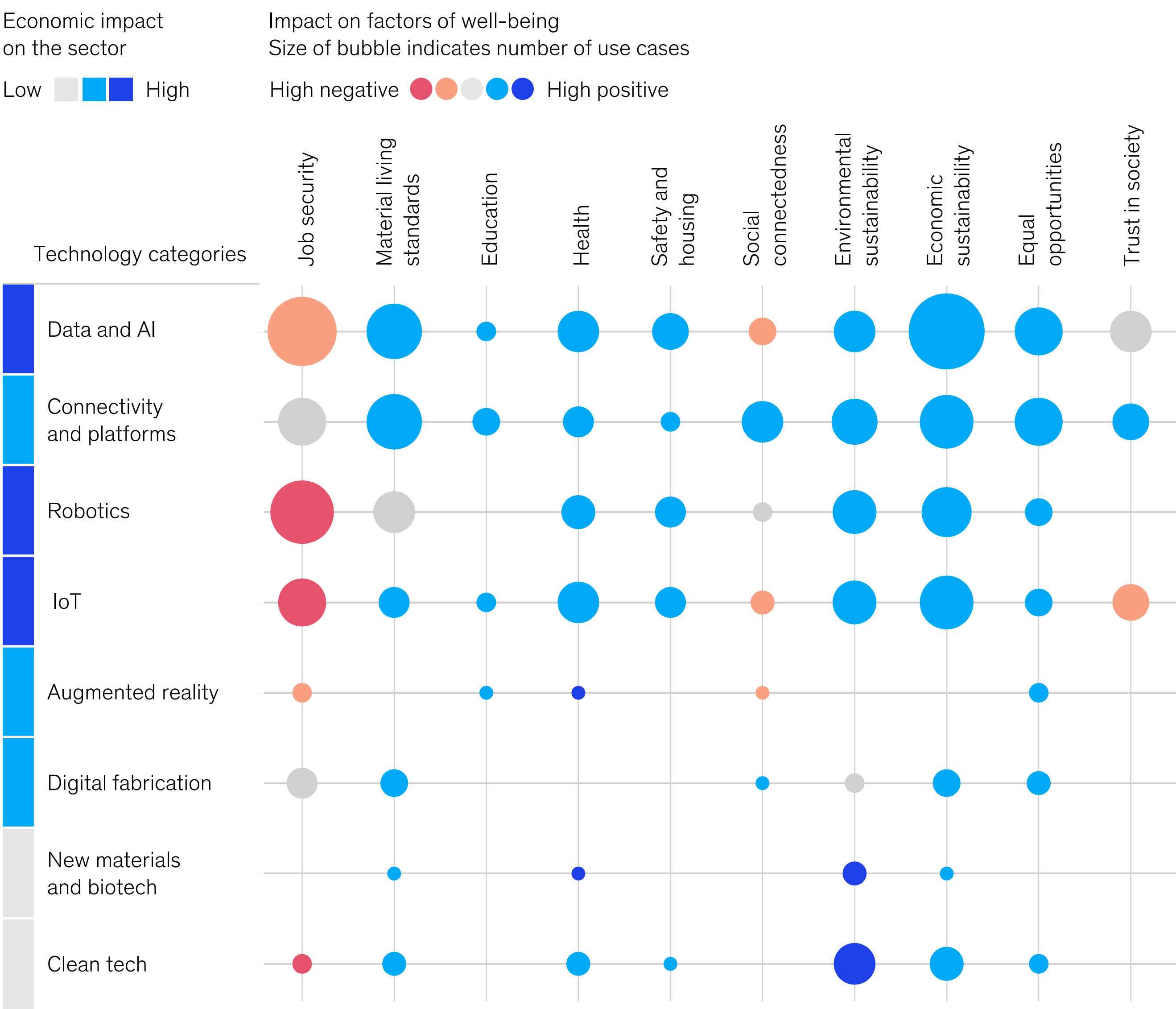
Exhibits 18 and 19 highlight areas where technology applications have a broadly positive impact on well-being, and where their impact is negative.

[187] Eurostat.

Exhibit 19

A large proportion of the use cases that create value for businesses also have a positive impact on many well-being factors.

Retail example



Note: Estimated economic impact based on expert calls, previous MGI reports, and press research. Size and colors of bubbles based on McKinsey Global Institute proprietary use cases library (~600 use cases in May 2019).

Source: McKinsey Global Institute analysis

Data and AI have the highest number of use cases (about 50 percent of use cases in the retail and manufacturing sectors), and the positive and negative effects are relatively evenly balanced, including some broadly net neutral impacts (marked in gray). A number of new technology applications run across multiple sectors: for example, AI-powered optimization of employee recruitment, evaluation, and training: AI-based R&D for new materials; and advanced analytics for truck or shipping route planning, for selling, general and administrative cost optimization, and for capital expenditure allocation. Other applications, such as condition-based and predictive maintenance, apply more specifically to the manufacturing sector. In the retail sector, while customer analytics and personalized notification systems are likely to boost profitability for retailers, price comparison platforms will play out in favor of consumers' purchasing power.

Automation can have negative implications for job security. Automated customer service management, for example, could potentially replace staffing in call centers. In retail stores, automatic ordering and replenishment of stock combined with automated checkout (using sensors in self-driving carts, for instance, or via smartphones) could reduce the number of employees. Robots could replace workers in manufacturing, to increase the efficiency of inventory management, for example. At the same time, multiple positive applications are possible and not yet fully implemented. For example, relatively inexpensive 3-D printers could help people start their own businesses. In manufacturing, augmented reality as well as AI-powered chatbots and training solutions could play a positive role when reskilling employees is required. Robots could be deployed to carry out dangerous tasks and protect workers' safety.

Economic sustainability is another area linked to business value where the impact of technologies is overwhelmingly positive. AI and automation could increase the total output for the same level of costs by optimizing operations in retail stores. For example, retailers could use hypercustomization to reduce returned products valued at more than $500 billion in 2020.[188] In manufacturing, the combination of data and AI with IoT technology (in single factories and across a network of factories) is also likely to yield huge productivity gains.

For material living standards, our use-case library suggests that the outcome is largely positive in both sectors, as efficiency gains and innovation benefit consumers.

Finally, the impact of technology on environmental sustainability is likely to be highly significant. In retail, while shifting customer habits will be key (for example, for new products such as plant- or insect-based food), IoT sensors and devices will also yield positive impact, for example reducing waste through improved food temperature or expiry date management. In the manufacturing sector, smart building applications related to energy and wastewater management, as well as applications such as carbon capture and biofuel generation on industrial sites, have a large impact potential.

The overall message is that, despite the potential short-term job security risks related to technology adoption, the overall positive impact of technology from these two sectors in economic sustainability, environmental sustainability, and even material living standards is likely to generate positive economic and welfare impacts.

A new imperative for business leaders

Companies can harness these benefits by adopting an approach of enlightened self-interest in the face of AI and automation adoption. At the company level, a workforce that is better trained, less stressed, healthier, and happier will also be more productive, more adaptable, and better able to drive the technology adoption and innovation surge that will boost revenue and earnings. At the broader level, a society whose overall welfare is

[188] *The plague of ecommerce return rates and how to maintain profitability*, Shopify, February 2019.

improving, and faster than GDP, is a more resilient society better able to handle sometimes painful transitions.

How can CEOs and boards set about meeting this imperative? We see three paths forward.

First, business leaders will need to understand and be convinced of the argument that proactive management of technology transitions is not only in the interest of society at large, but also in the more narrowly focused financial interest of companies themselves. This paper is an opening salvo. More work will be needed, including to show how and where individual sectors and companies can benefit from using the Tech for Good tools we have outlined here.

Second, the focus on innovation and the accompanying proactive management will need to be embedded in company plans for technology adoption in this AI era. They are essential ingredients for successful digital reinvention. Our prior work has shown the comparative advantage of digital leaders who use automation and AI as tools to innovate and create new products and services, generate new business models, and develop new markets. Automation as a tool for labor substitution can bring gains to earnings, but in the longer term, our research has shown, that approach amounts to a lost opportunity for more fundamental reinvention.[189] Moreover, talent is emerging as a differentiating factor. Training, retraining, and nurturing individuals with the skills needed to implement and operate updated business processes and equipment will be critical. From that perspective alone, active management of training and mobility will be an essential task for boards in the future.

Third, this is not a task for business on its own. The successful adoption of AI and other advanced technologies will require cooperation by multiple stakeholders, especially business leaders and the public sector. The public and private sectors will have roles to play in the proactive management of technology adoption. Education and skills are one example: business leaders can help inform education providers with a clearer sense of the skills that will be needed in the workplace of the future, even as they look to raise the specific skills of their own workforce. Other critical public-sector actions include supporting R&D and innovation; creating markets for public goods, such as health, so there is a business incentive to serve these markets; and collaborating with businesses on reskilling and worker matching. A more fluid labor market and better job matching will benefit companies and governments, accelerating the search for talent for the former and reducing the potential transition costs for the latter. A healthier workforce will likewise be advantageous to all.

Just as technologies are evolving, so too are attempts to measure well-being and the factors that contribute to it. This paper is an early attempt to combine the two into an examination of how frontier technologies may affect well-being beyond GDP, both positively and negatively. For all the necessary caveats, our overall finding is an optimistic one: with proactive management and a focus on innovation-led technology adoption, society as a whole could see significant net welfare benefits. Yet positive outcomes will not happen by themselves. Moreover, given that inequalities and risks are likely to persist, market-based incentives may not be enough to get societies to their target state. Governments, businesses, and individuals all have roles to play in ensuring both that the welfare-enhancing opportunities presented by AI, automation, and other technologies are embraced and that technology-related transitions are well managed.

The nexus between technology and welfare is an important one, and our hope is that this paper will stimulate deeper research and broad discussion to bring it into clearer focus.

[189] Jacques Bughin, Laura LaBerge, and Anette Mellbye, “The case for digital reinvention,” *McKinsey Quarterly*, February 2017; Jacques Bughin and Tanguy Catlin, “What successful digital transformations have in common,” *Harvard Business Review*, December 19, 2017.

Technical appendix

This appendix provides details of the scope, approach, methodology, and data sources used in the analysis for this discussion paper. It is arranged in the following sections:

1. Scope
2. Well-being framework
3. Scenarios
4. Welfare calculation methodology
5. Historical comparisons
6. Main data sources and assumptions
7. Use-case library

1. Scope

This discussion paper aims to provide a perspective on the impact on welfare of different technology adoption paths. Welfare refers to the socioeconomic value of the impacts of technology adoption in GDP-equivalent terms. It consists of GDP and an additional set of non-GDP elements, such as health, consumption, inequality, and leisure.

To provide a fact base on the use of technologies and their likely effect (either positive or negative), we rely on two sources: a broad review of about 600 use cases (see "Use-case library" below), and an extension of a GDP-based model of production and diffusion used in previous MGI research.[190] The analysis is focused on a current set of frontier technologies which include digital and automation tools as well as artificial intelligence, smart robotics, and the Internet of Things. Certain technologies are included in the use-case library but excluded from the modeling due to parallel work by MGI or lack of reliable estimates on quantitative impact. These include augmented and virtual reality, new materials, biotechnology, and environmental technology.

The model is calibrated to the economies of the 28 European Union member states and the United States. The timeframe considered is from 2017 to 2030. 2017 is used to construct a baseline using available data from sources including the OECD, Eurostat, and the World Health Organization. Where data for a particular country are not available for 2017, the most recent year is used. 2030 is chosen as far enough into the future to enable us to draw a contrast to today and to take an informed initial view on the potential positive and negative effects to which the economy and society might be subject due to technological transitions. Note that by 2030, we expect that the macro-economic welfare impacts will be largely

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

driven by the current set of known technologies. Moreover, the full transition effects of these technologies are likely to take a long time, such that by 2030, diffusion will have reached only about 50 percent of the total economy. For example, we assume that technologies such as general AI or quantum computing will not be mainstream by 2030. These assumptions are in line with previous MGI work as well as external experts' analysis.[191]

2. Well-being framework

The 10 dimensions of the well-being framework are chosen based on an analysis of multiple existing frameworks that are in use around the world (Exhibit A1), including among others the OECD Better Life Index, the Stiglitz Commission framework, the UN's Sustainable Development Goals, and selected national frameworks such as the New Zealand Living Standards Framework, along with empirical findings of the impact of different factors on the well-being of individuals and societies.[192]

While these frameworks overlap, they also have certain differences in prioritization and approach. For example, the Sustainable Development Goals framework dedicates seven out of 17 values to environment-related concerns, while the OECD has only one broad category called environment. The OECD Better Life Index is our primary inspiration due to its breadth and balanced nature. In adopting it, we make two changes necessary to support our approach:

First, we explicitly add an intergenerational aspect, changing environment to environmental sustainability and adding economic sustainability. Second, we focus on factors that are relatively objective in nature and tend to drive overall well-being outcomes. We therefore exclude life satisfaction and work-life balance, given that they are primarily the outcomes of other factors already in the framework.

Where necessary, we have changed the names of the factors to more fully reflect the purpose of this work.

[191] Larry Greenmeier, "How close are we—really—to building a quantum computer?," *Scientific American*, May 2018; *Testing the resilience of Europe's inclusive growth model*, McKinsey Global Institute, December 2018.

[192] See United Nations' Sustainable Development Goals; OECD's Better Life Index; Human Development Index; New Zealand Living Standards Framework; Joseph E. Stiglitz, Amartya Sen, and Jean-Paul Fitoussi, *Report by the Commission on the Measurement of Economic Performance and Social Progress*, 2009; Michael E. Porter and Scott Stern, *Social progress index, Social Progress Imperative*, 2017; Ed Diener et al., "Social well-being: Research and policy recommendations," in John F. Helliwell, Richard Layard, and Jeffrey D. Sachs (eds.), *Global Happiness Policy Report: 2018*, Global Council for Happiness and Well-being, 2018; Kirk Hamilton and Cameron Hepburn, *National wealth: What is missing, why it matters*, Oxford Scholarship Online, October 2017; Richard Layard, *Measuring wellbeing and cost-effectiveness analysis. Using subjective wellbeing*, Discussion Paper 1, Centre for Economic Performance, December 2016.

Exhibit A1

Different approaches are taken to categorize elements of societal well-being.

Bhutan's Gross National Happiness
- Psychological well-being
- Health
- Education
- Time use
- Cultural diversity and resilience
- Good governance
- Community vitality
- Ecological diversity and resilience
- Living standards

Eurofound (work)
- Physical environment
- Work intensity
- Working time quality
- Social environment
- Skills and discretion
- Prospects
- Earnings

Maslow's Hierarchy
- Physiological needs
- Safety needs
- Belongingness and love needs
- Esteem needs
- Self-actualization

OECD Better Life Index
- Housing
- Income
- Jobs
- Community
- Education
- Environment
- Civic engagement
- Health
- Life satisfaction
- Safety
- Work-life balance

Resolution Foundation
- Incomes and inequality
- Jobs, skills, and pay
- Housing, wealth, and debt
- Tax and welfare
- Public finances and the economy

Social Progress Index
- Basic human needs (nutrition and basic medical care, water and sanitation, shelter, personal safety)
- Foundations of well-being (access to basic knowledge, access to ICT, health and wellness, environmental quality)
- Opportunity (personal rights, personal freedom and choice, inclusiveness, access to advanced education)

Stiglitz Commission
- Material living standards (income, consumption, and wealth)
- Health
- Education
- Personal activities, including work
- Political voice and governance
- Social connections and relationships
- Environment
- Insecurity, of an economic as well as physical nature

Taylor Review on Work Practices
- Wages
- Employment quality
- Education and training
- Working conditions
- Work-life balance
- Consultative participation and collective representation

WB Changing Nature of Work
- Nature of work
- Nature of firms
- Human capital
- Lifelong learning
- Returns to work
- Social protection
- Social inclusion

WEF Inclusive Development Index
- Growth and development
  - GDP per capita
  - Labor productivity
  - Healthy life expectancy
  - Employment rate
- Inclusion
  - Net income gini
  - Poverty rate
  - Wealth gini
  - Median income
- Intergenerational equity and sustainability
- Adjusted net savings
- Carbon intensity
- Public debt
- Dependency ratio

WHO Healthy Workplaces
- Physical work environment
- Personal health resources
- Enterprise community involvement
- Psychosocial work environment
- Leadership engagement
- Ethics and values

UK measure of national well-being
- Personal well-being
- Our relationships
- Health
- What we do
- Where we live
- Personal finance
- The economy
- Education and skills
- Governance
- The natural environment

UN Human Development Dashboard
- Quality of human development
- Life course gender gap
- Women's empowerment
- Environmental sustainability
- Socioeconomic sustainability

UN Human Development Index
- Long and healthy life (life expectancy at birth)
- Knowledge (expected years of schooling, mean years of schooling)
- A decent standard of living (GNI per capita PPP USD)

UN Sustainable Development Goals
- No poverty
- Zero hunger
- Good health and well-being
- Quality education
- Gender equality
- Clean water and sanitation
- Affordable and clean energy
- Decent work and economic growth
- Industry, innovation, and infrastructure
- Reduced inequalities
- Sustainable cities and communities
- Responsible production and consumption
- Climate action
- Life below water
- Life on land
- Peace, justice, and strong institutions
- Partnerships for goals

Source: McKinsey Global Institute analysis

3. Scenarios

In our simulation of the impact of technology paths on welfare, we define three internally consistent scenarios in three quadrants of a 2-by-2 plane. The x-axis refers to the focus of technology adoption (that is, on labor substitution and cost reduction, or innovation-led, human-centric growth) and the y-axis to how technology related transitions are managed (that is, reactively or proactively). Exhibit A2 describes the different assumptions about economic actors' prioritization decisions and the high-level logic of outcomes in the three scenarios.

As mentioned in the "Welfare calculation methodology" section, we use a market-based equilibrium model to quantify impacts on welfare. The different scenarios should therefore be considered "what if" simulations that assume a set of choices and decisions by businesses and government that are compatible with the incentives facing them. This means that any implied choices, while potentially better or worse for the overall outcome, have a positive economic return for the actors involved and therefore do not assume large scale nonmarket intervention (Exhibit A3).

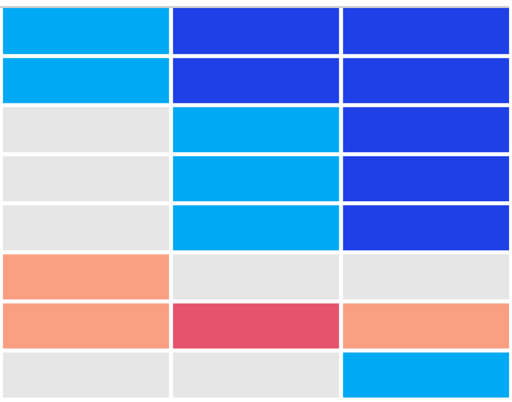
Exhibit A2

Prioritization of different actions by economic actors varies by scenario.

Key impact on economy and society
High negative ■■■■■ High positive

● Encouraged/prioritized
○ Discouraged/not prioritized

Scenario quadrant		Low growth, low welfare	High growth, low welfare	Tech for better lives
Potential government priorities	Enabling legislation	○	●	●
	Support to R&D investment	○	●	●
	Support to reskilling, incl. by using technology	○	○	●
	Flexible labor markets, incl. by using technology	○	○	●
	Active creation of markets for "technology for good," incl. deployment in public services	○	○	●
Potential business priorities	Adopt existing technology to drive productivity	●	●	●
	Invest in R&D for new technology and applications	○	●	●
	Innovate new products, services, and business models	○	●	●
	Deploy technology for reskilling and talent matching	○	○	●
	Prioritize technology adoption that is good for both business and societal well-being	○	○	●
Key impacts on economy and society	Productivity			
	Lower real prices			
	Wages			
	Demand			
	Output			
	Employment			
	Equality			
	Health			



Source: McKinsey Global Institute analysis

Exhibit A3

Government and business can take a variety of actions in the different scenarios.

Actor group	Low growth, low welfare	High growth, low welfare	Tech for better lives
Governments	Do not support, and, in certain areas, even discourage, the diffusion of new technologies, prompted potentially by concern about transition risks. This involves: • Scaling down spend on basic research, which will render some innovation uneconomic (public good) and likely reduce business R&D (which is strongly correlated with public funding) • Lack of acceleration of technology adoption in public services (a significant economic actor but currently adopting at a much slower pace than the private sector) • Lack of focus on enabling workforce reskilling to enable rapid technology adoption and productivity growth	• Actively encourage investment in, and adoption of, digital technology, automation and AI • Do not, however, facilitate reskilling or use technology to create flexibility in labor markets • Do not actively create effective markets for “Tech for Good,” or accelerate digital adoption in public administration	• Actively encourage adoption of digital technology, automation, and AI, eg, through enabling legislation • Facilitate investment in reskilling and use technology to create flexibility and improve matching in labor markets (eg, through digital and AI platforms) • Create effective markets for “Tech for Good” to improve effectiveness and efficiency of health and other public services
Businesses	• Focus technology adoption on cost reduction and labor saving through automation and scale down innovation efforts, as their return on investment is reduced	• Respond through fast adoption of existing digital, automation, and AI technology where it makes commercial sense • Invest more in development of new technology, and new applications for existing technology • Put significant effort into innovating new products, services, and business models • Reskill workforce in line with their business needs	• Respond through fast adoption of existing digital, automation, and AI technology • Invest more in development of new technology and new applications for existing technology • Put significant effort into innovating new products, services, and business models • Reskill workforce in line with their business needs
Both	• Do not deploy large amounts of technologies aimed at improving societal well-being	• Do not deploy large amounts of technologies to manage the technology transition	• Prioritize technologies specifically aimed at managing the technology transition, such as reskilling, labor market mobility and talent matching applications, and health applications

Source: McKinsey Global Institute analysis

4. Welfare calculation methodology

We use an equilibrium model with multiple interconnected feedback loops to simulate the impact of various aspects of technology adoption and diffusion on GDP and overall welfare (Exhibit A4).

Key feedback loops of the model include:

- Unemployment, underpinning five out of six components of overall welfare, is influenced by shifts in demand for skills, as well as transitional unemployment, defined by the level of mobility in the labor market, that is, ability of employees to acquire new skills and find a new position. The components of mobility are defined as mobility within firms and between firms, understood as mobility within sectors and between sectors. Greater unemployment is linked to diminishing income for labor, lower cumulated labor productivity, and higher forced leisure. Risk of unemployment leads to lower consumption, as savings increase in order to safeguard against market uncertainty. Unemployment itself is affected by a range of factors. While the increase in job mobility has the potential to lower unemployment, increased automation can potentially lead to labor substitution.

- Consumption inequality consists of inequality in wages, inequality in incomes due to unemployment, and inequality due to shifts in the capital/labor share. Increased technology diffusion and a faster automation rate are assumed to increase the share of total GDP accruing to capital versus labor. It therefore translates to consumption inequality, as ownership of capital is typically concentrated among top-earning households. We add this to the changes in inequality due to unemployment and wage differences. These wage differences are a function of the supply and demand of different types of skills in each of the technology scenarios.

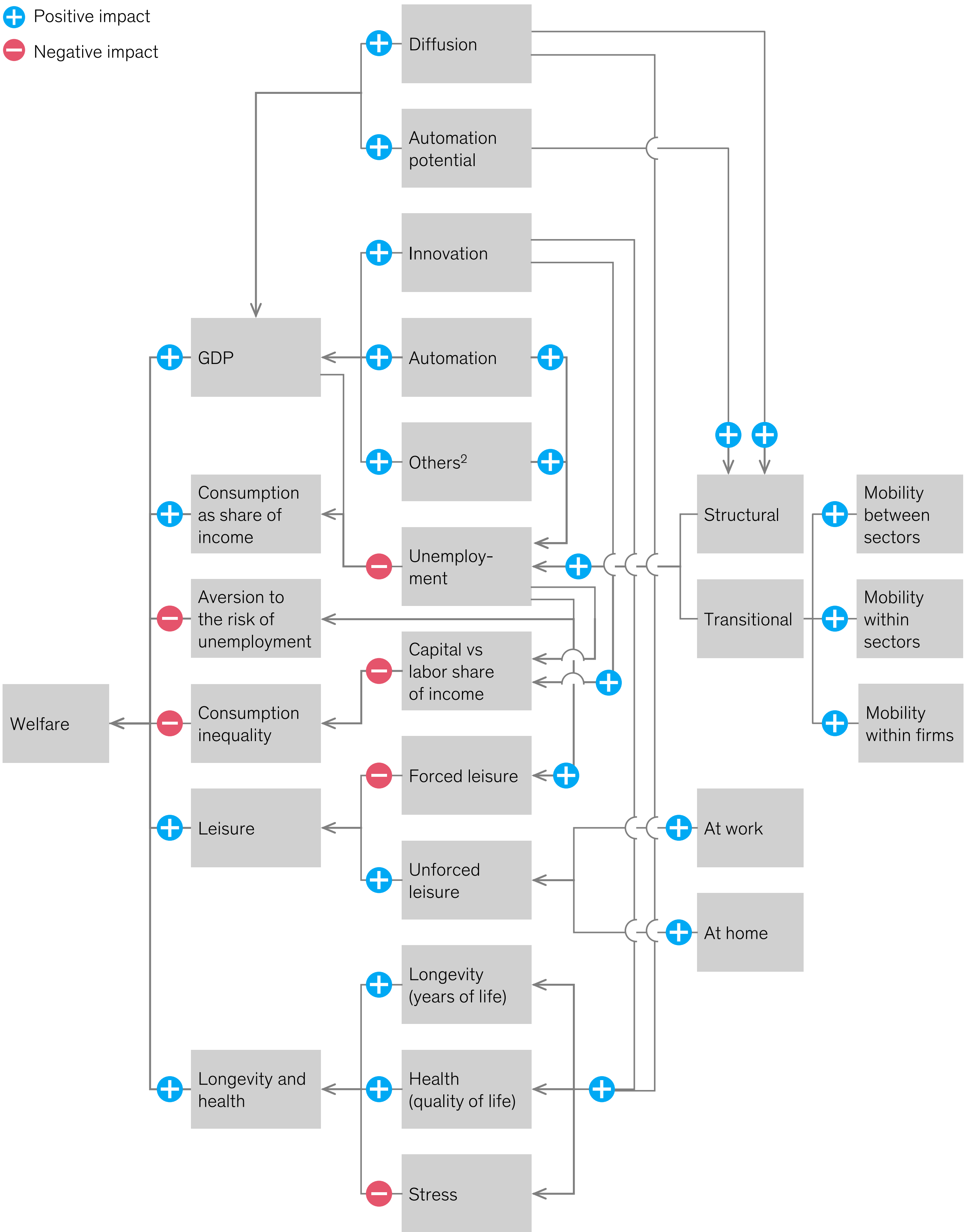
5. Historical comparisons

Exhibits A5 and A6 show historical growth of welfare by component based on the work of other researchers, to provide context for interpreting our modeling results.

Exhibit A4

The welfare model incorporates dynamics among its key component factors.

Economic outcomes included in welfare calculation[1]



1 Only first level of dependencies; eg, not considering Education which is the key enabler of job security and material living standards, or the positive feedback loop from better health to productivity.
2 Encompasses productivity levers such as Augmentation, Substitution, and Wealth creation.

Source: McKinsey Global Institute analysis

Exhibit A5

Growth in total net welfare in the European Union and the United States declined after the financial crisis.

Compound annual growth rate,[1]
%

	Historical welfare growth, 1980–2007		Historical welfare growth, 2007–14	
	US	EU-28	US	EU-28
Total net welfare	3.1	3.2	2.3	2.6
GDP growth	2.1	2.3	2.0	1.1
Longevity	0.9	1.3	0.8	1.3
Health	n/a	n/a	n/a	n/a
Stress	n/a	n/a	n/a	n/a
Consumption inequality	-0.2	0.0	-0.1	0.0
• Wage inequality	n/a	n/a	n/a	n/a
• Capital/labor inequality	n/a	n/a	n/a	n/a
Consumption as a share of income	0.4	-0.2	-0.2	0.3
Aversion to the risk of unemployment	n/a	n/a	n/a	n/a
Leisure	-0.1	-0.2	-0.3	-0.1

1 See Frantisek Brocek and Tibor Lalinsky, *Welfare in Slovakia and the EU—an alternative to GDP per capita*, MPRA paper 83456, 2017: 17–23; Geoffrey J. Bannister and Alexandros Mourmouras, *Welfare vs. income convergence and environmental externalities*, International Monetary Fund Working paper number 17/271, November 2017; Charles I. Jones and Peter E. Klenow, “Beyond GDP? Welfare across countries and time,” *American Economic Review*, September 2016, Volume 106, Number 9.

Source: McKinsey Global Institute analysis

Exhibit A6

An historical comparison of ICT-driven welfare growth in the European Union and the United States.

Compound annual growth rate,[1]
%

	Historical welfare growth driven by ICT, 1980–2007		Historical welfare growth driven by ICT, 2007–14		Historical welfare growth driven by ICT, weighted by population	
	US	EU-28	US	EU-28	1980–2007	2007–14
Total net welfare	1.0	1.2	0.4	1.0	1.1	0.8
GDP growth	0.8	0.7	0.4	0.4	0.7	0.4
Longevity	0.3	0.4	0.2	0.4	0.3	0.3
Health	0.1	0.2	0.1	0.2	0.2	0.2
Stress	n/a	n/a	n/a	n/a	n/a	n/a
Consumption inequality	-0.2	-0.1	-0.3	-0.2	-0.1	-0.2
• Wage inequality	-0.1	-0.1	-0.2	-0.1	-0.1	-0.1
• Capital/labor inequality	-0.1	0.0	-0.2	-0.1	0.0	-0.1
Consumption as a share of income	0.1	-0.1	-0.1	0.1	0.0	0.0
Aversion to the risk of unemployment	n/a	n/a	n/a	n/a	n/a	n/a
Leisure	-0.1	0.1	0.1	0.1	0.0	0.1
Negative components as a share of total gross welfare	33.3	20.0	66.7	28.6	15.4	33.3

1 See Frantisek Brocek and Tibor Lalinsky, *Welfare in Slovakia and the EU—an alternative to GDP per capita*, MPRA paper 83456, 2017: 17–23; Geoffrey J. Bannister and Alexandros Mourmouras, *Welfare vs. income convergence and environmental externalities*, International Monetary Fund Working paper number 17/271, November 2017; Charles I. Jones and Peter E. Klenow, “Beyond GDP? Welfare across countries and time,” *American Economic Review*, September 2016, Volume 106, Number 9.

Source: McKinsey Global Institute analysis

6. Main data sources and assumptions

We base our estimates on a range of data sources and supplement them by a range of secondary estimates, gathered from meta-analysis of academic literature. We also consider a battery of surveys, to triangulate the most important factors of social welfare, and build on past MGI efforts. The use-case library (see below) is also used to calibrate the estimates. The data sources and assumptions for the main model inputs can be split into those for the starting point (average scenario) and those for the three different future scenarios. The main data sources and assumptions are presented in Exhibit A7.

Exhibit A7

The key assumptions and data sources we used for our welfare modeling.

Component	Indicator	Definition	Key assumptions, Average scenario	Key assumptions for other scenarios
Technology adoption and diffusion	Diffusion	The rate at which productivity-enhancing technology is adopted by economic agents	50% of firms adopt new frontier technologies by 2030	Sensitivity within 40–60% range
	Automation potential	The percentage of tasks that could be automated by adapting currently demonstrated technology	45% of hours currently worked can be automated	Automation potential stays constant, as it is based on already demonstrated technology
	Automation	Substitution of workers by technology	48% of potential additional economic output	Output of the model driven by change of level of innovation
	Innovation	Innovation ability and the technological skills of the workforce	27% of potential additional economic output	Range of 22% to 33% (from reduction by 10% to increase by 10%, followed by normalization)
	Augmentation	Augmentation understood as technology that makes humans more productive	9% of potential additional economic output	Output of the model driven by change of level of innovation
	Connectedness	Data connectedness and connectivity to the world	7% of potential additional economic output	Output of the model driven by change of level of innovation
	Wealth creation	Increase in return on investment in technological progress	9% of potential additional economic output	Output of the model driven by change of level of innovation
Unemployment	Structural unemployment	Long-term unemployment resulting from mismatch between skills required by employers and skills available in the workforce	Output of the model	Output of the model
	Transitional unemployment	The probability of finding a job within a year, once the job is lost	• 90% of mobility within firms • 80% of mobility between firms, within sector • 70% of mobility between firms that are in different sectors	• 81–99% of mobility within firms • 72–88% of mobility between firms, within sector • 63–77% of mobility between firms in different sectors

Source: McKinsey Global Institute analysis

Exhibit A7 (continued)

The key assumptions and data sources we used for our welfare modeling.

Component	Indicator	Definition	Key assumptions, Average scenario	Key assumptions for other scenarios
Consumption inequality	Capital vs labor share of income	Share of income accruing to capital as opposed to labor	• 20% share of capital owners in population • 50% income share of capital	• 20–24% share of capital owners in population • 40–50% income share of capital
Leisure	Voluntary leisure and forced leisure	Quantity and quality of time spent when not working; unemployment is considered forced leisure	• 1% of leisure utility gained due to productivity at work • 0.2% of leisure gained due to productivity at home	• 1–2% of leisure utility gained due to productivity at work • 0.1–0.4% of leisure utility gained due to productivity at home
Longevity and health	Longevity (years of life)	Value and utility of extended life span	40% of longevity improvement driven by technology, approx. in line with historical rate	Range of 40% to 48%
	Health (quality of life)	Value and utility of improved health	Health utility improves at 50% of rate of longevity	Range of 50% to 72%
	Stress	Health effect of changes to work related stress	-25% offset to improvement of health due to stress	Range of 23% to 28%

Note: For technology adoption and diffusion, see *Notes from the AI frontier: Modeling the impact of AI on the world economy*, McKinsey Global Institute, September 2018, and *Jobs lost, jobs gained: Workforce transitions in a time of automation,* McKinsey Global Institute, December 2017. For consumption inequality and total factor productivity, see Florence Jaumotte and Carolina Osorio, *Inequality and labor market institutions*, International Monetary Fund, 2015; for relation between increase in ICT, total factor productivity, and income, see Ben Miller and Robert Atkinson, *Raising European productivity growth through ICT*, ITIF, June 2014; YiLi Chen, *What drives long-run economic growth?* Federal Reserve Bank of St . Louis, 2015; Werner Roeger, *The contribution of information and communication technologies to growth in Europe and the US: A macroeconomic analysis*, European Communities, 2001; David M. Byrne, Stephen D. Oliner, and Daniel E. Sichel, *Is the Information Technology Revolution Over?* SSRN Scholarly Paper, March 2013; *World Economic Outlook, April 2017: Gaining Momentum?* International Monetary Fund, April 2017. We assume that leisure is linked to labor productivity and look at contribution of ICT to labor productivity; we use as base of our analysis Desirée van Welsum, Willem Overmeer, and Bart van Ark, *Unlocking the ICT growth potential in Europe: Enabling people and businesses: Using Scenarios to Build a New Narrative for the Role of ICT in Growth in Europe*, European Commission, 2001. On longevity we take estimates in the literature of the impact of technology innovation on medicine and pharmaceuticals and on longevity; see Katarina Steen Carlsson and Bengt Jönsson, "Valuing new medicines in the early 21st century," *Nordic Journal of Health Economics*, 2017; Seema Jayachandran, Adriana Lleras-Muney, and Kimberly V. Smith, "Modern medicine and the twentieth century decline in mortality: Evidence on the impact of sulfa drugs," *American Economic Journal*, 2010; Frank R. Lichtenberg, "The impact of biomedical innovation on longevity and health," *Nordic Journal of Health Economics*, Volume 5.1, 2015.

Source: McKinsey Global Institute analysis

7. Use-case library

For this discussion paper, we curated a library of about 600 technological use cases that have relevance for the societal well-being factors identified. Our research includes a literature review, a meta-analysis of various sources, and collation of data from existing McKinsey and MGI use-case libraries. We leverage frameworks and analyses conducted by various foundations and institutions such as the OECD, the International Telecommunication Union and Ellen MacArthur Foundation. This effort was complemented by an extensive press search to ensure that the use cases in our library are up to date and relevant.

We assign each of the use cases to a specific technology category, utilizing existing MGI frameworks. Since some use cases encompass multiple technologies at once, they were assigned to several technology categories. Similarly, it is often the case that a use case can affect multiple factors of well-being. In such cases, a use case would be represented in several cells of Exhibit A8.

Exhibit A8

Use cases are assigned to each of the well-being factors by technology category.

	Data and AI	Connectivity and platforms	Robotics	IoT	AR/VR	Digital fabrication	New materials and biotech	Clean tech
Job security	31	38	8	2	7	3	4	4
Material living standards	58	54	14	19	4	12	13	22
Education	45	46	5	5	8	0	0	1
Health	100	40	33	28	4	3	13	20
Safety and housing	76	30	21	39	0	5	6	7
Social connectedness	45	49	10	9	1	1	0	3
Environmental sustainability	72	30	42	49	2	14	44	87
Economic sustainability	81	37	37	37	7	11	14	28
Equal opportunities	71	68	20	18	4	4	1	5
Trust in society	85	56	15	29	0	0	1	8

Source: McKinsey Global Institute analysis

Acknowledgments

This discussion paper is part of our ongoing research that explores aspects of artificial intelligence and other frontier technologies and their potential impact on business, the economy, and society. Previous papers have looked at automation's potential effect on work, changing workforce skill requirements, AI use cases across sectors and business functions, and AI's potential impact on the global economy.

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