03

Impact Series

Robots at the gate: Humans and technology at work

Technological advances are generating fears of a jobless future. At the same time, major economies are seeing historically low unemployment rates and wage growth is puzzlingly low. Find out how technology is changing the nature of work, not eliminating it.

BARCLAYS

Foreword

Welcome to the third report in our Impact Series, in which we analyse the wide-ranging impacts of technological advancement on how people work today, and possibly will work in the future.

April 11, 2018

Humans have often had a cautious relationship with new technology, particularly when it causes widespread disruption in the workforce. Yet historically, technological advances have not resulted in fewer jobs available to humans, but rather have led to the creation of new opportunities. Farriers and saddlemakers were hit hard when cars replaced horse carriages, but the petrol stations, mechanics, motels and related industries that sprung up created new, yet different, types of jobs. More recently, the smartphone is a great example of technological advances creating new forms of work. Twenty years ago, mobile app developer was not a job; today, millions of such developers are at work around the world.

There is a growing sense that the age of Artificial Intelligence and machine learning is ushering in a new era of opportunity, but also great uncertainty and dislocation. The fact that robots are coming ever closer to acting and thinking like humans shines an acute light on what technological advancement could mean for the lives of working people.

This report explores the confluence of current technological advancements and whether machines are about to permanently replace humans in the workplace, while also digging deeper into two automation-related quandaries: the absence of wage inflation despite record low unemployment in major economies, and low labour productivity despite technological advancements.

I hope the insights delivered by our Research analysts will help stimulate the debate needed to ensure global societies are able to adapt and thrive as the nature of work continues to evolve.

Jes Staley
Chief Executive Officer, Barclays

Technology and the future of work

Over the centuries, technological progress has evoked both fear and fascination, especially in terms of the impact on labour. Even as the Industrial Revolution forever changed the trajectory of human progress, leading voices of the 19th century remained divided on how it could affect workers. One of the most influential economists of all time, David Ricardo, flip-flopped on the issue. In 1821, he stated that while he had previously felt that using machinery in production was a general good, he was now more worried about the substitution effect on labour. And the discussion was not always academic – the Luddite movement was an early example of workers resorting to violence to protest the use of technology in textile factories.

As the decades passed, the Industrial Revolution led to a visible, massive improvement in living standards. But the debate – on how technology affects work and whether it is an unequivocal positive – continued to wax and wane. It reared its head again in the 1960s, when US President Lyndon Johnson set up a commission to study the impact of automation on jobs. The commission noted that "technology eliminates jobs, not work." But it did acknowledge that the pace of technology on the workforce was severe enough that the government considered radical measures such as "guaranteed minimum income" and "government as the employer of last resort."

In the past few years, the debate has been renewed. Technological luminary Bill Gates has suggested that it might be time to tax robots. The idea of a basic universal income has resurfaced, with Finland launching a two-year pilot last year. Elon Musk of Tesla and Facebook's Mark Zuckerberg engaged in a public war of words a few months ago on the risks and opportunities of Artificial Intelligence (AI).[1] Futurists such as Ray Kurzweil have been relentlessly optimistic about the impact of a new generation of technological improvements. The International Monetary Fund (IMF), the Organisation for Economic Co-operation and Development (OECD), as well as think tanks such as the McKinsey Global Institute (MGI), have all published studies discussing how advances in machine learning and robotics could fundamentally reshape the global workforce.

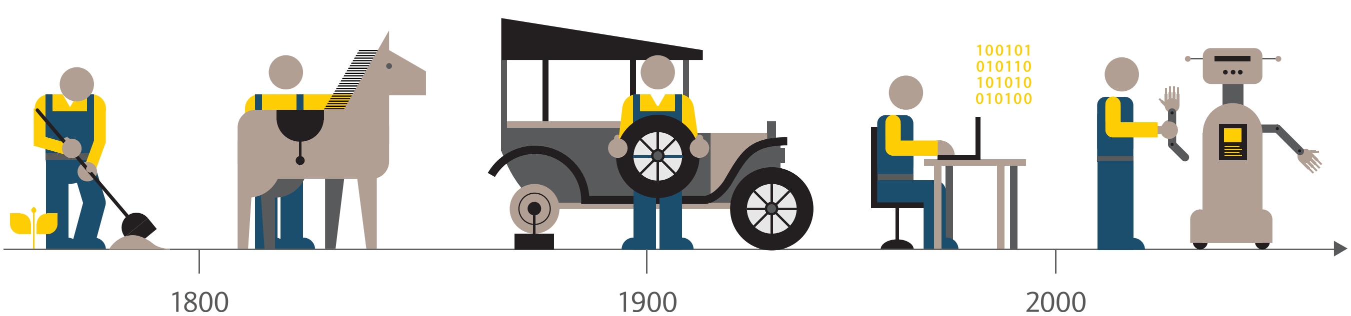
Meanwhile, central bankers from around the world believe technology is one reason why super-low unemployment rates have failed to cause sharp rises in wage inflation. After taking a few decades off, the age-old debate – on how technology will change the future of work – is back with a vengeance. To understand this phenomenon, we first look at ways in which human skill-sets differ from machines.

"The basic fact is that technology eliminates jobs, not work."

– From 1966 report by the US National Commission on Technology, Automation, and Economic Progress

Figure 1

The evolution of work over 250 years



Source: Barclays Research

1 https://www.usatoday.com/story/tech/news/2018/01/02/artificial-intelligence-end-world-overblown-fears/985813001/

Waiting for the next generation

The concept of a sentient machine that can do everything humans can and more has been part of pop culture for decades, especially since the first Terminator movie in 1984. But there is an even longer history of mankind's fascination with the concept of an all-powerful Artificial Intelligence. In 1957, the US Navy developed an early generation AI called Perceptron using early-stage artificial neural networks. After a press conference by its creator, Frank Rosenblatt, the New York Times reported that the US Navy expected this new machine to be able to "walk, talk, see, write, reproduce itself and be conscious of its existence."[2] Six decades later, we are still waiting for that next-generation AI to arrive.

Even as machines made significant inroads into the workplace, humans have historically retained a huge advantage in two areas:

Sensorimotor skills

Humans can process input from their senses in the physical world and perform tasks based on that input. A robotics researcher at Carnegie Mellon, Hans Moravec, famously articulated this in what is now called Moravec's paradox. He pointed out that higher-level reasoning takes far less computational resources for a machine than even low-level sensorimotor skills.

Machines have progressed to the point where they can convince us that we are talking to a human, but even very advanced robots are far clumsier physically than a young child. Marvin Minsky, founder of the Massachusetts Institute of Technology's AI laboratory, noted that the most difficult human skills to re-create in a machine were those that were unconscious to us, such as the ability to do simple tasks such as unscrew a jar lid or walk over uneven terrain.[3]

Cognitive functionality

The other area where humans are superior relates to our capacity to learn, perceive, understand context and make decisions based on often incomplete information. Consider something as simple as content moderation, the task of making sure that objectionable views are not posted on social media. Every social media site has added thousands of content moderators in recent years, including titans such as Facebook and Instagram. One would expect these technological leaders to use machines for this purpose, so why do they keep hiring human moderators? Because machines are unable to distinguish between what humans instinctively know as right or wrong. Aaron Schur, senior director of litigation at Yelp, recently noted that machines cannot understand if a user is posting a racist review or merely describing racist behaviour.[4] One is objectionable, the other is not.

Context is key, but computers cannot understand it. Decades ago, US Supreme Court Justice Potter Stewart made the same point. When describing his threshold test for "hard-core pornography," he famously uttered the phrase, "I know it when I see it." Humans know how to make such subjective judgments. Machines don't.

Figure 2

Humans' main advantages over robots

Source: Barclays Research

2 "New device learns by doing", *The New York Times*, July 8, 1958 – while the NY Times link is not available, please see a digital link to a 1996 paper where the NY Times article is quoted – https://pdfs.semanticscholar.org/f3b6/e5ef511b471ff508959f660c94036b434277.pdf

3 https://en.wikipedia.org/wiki/Moravec%27s_paradox

4 https://www.law.com/therecorder/sites/therecorder/2018/02/05/5-takeaways-from-tech-leaders-content-moderation-conference/

Polanyi's Paradox

In 1966, philosopher Michael Polanyi wrote a book called *The Tacit Dimension*, which argued that human knowledge is often "tacit" – learned by us through cultural memory, tradition, etc. Humans learn from experience – indeed, that has arguably been the driver of humanity's progress over the centuries – while machines do not. As a result, humans have skills and abilities that are second nature and easy for us to do, but extremely difficult for computers to imitate.

Polanyi's paradox states that we "know more than we can tell." Many of the tasks that humans perform without thinking every day are because of our tacit knowledge, which is difficult to articulate.

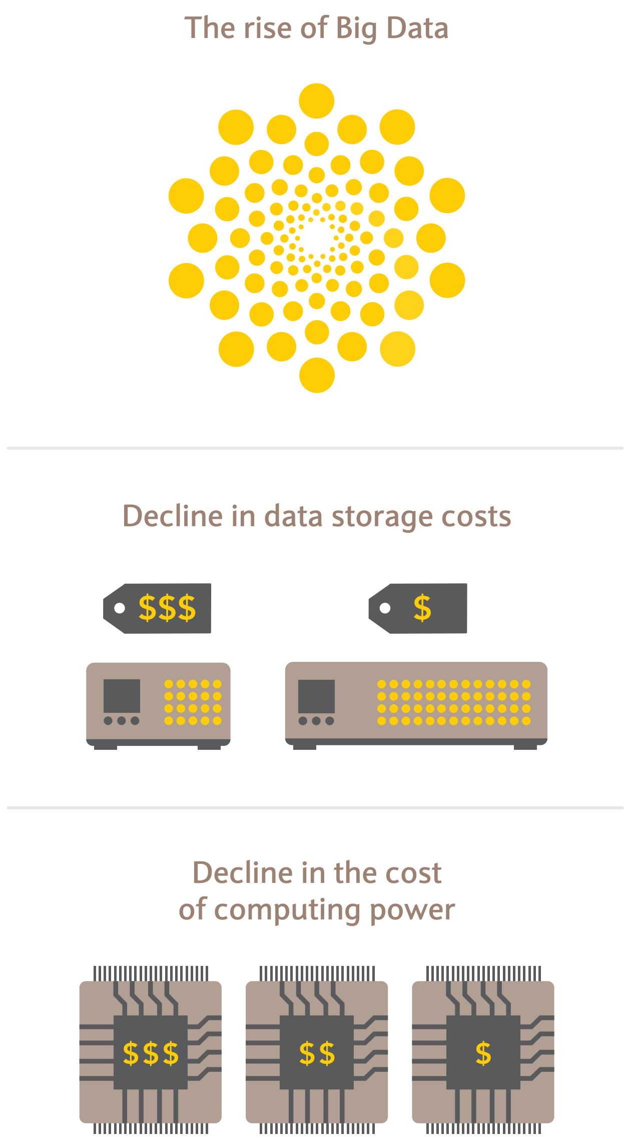
But if we cannot describe this knowledge, how can we codify it in a way that machines can understand? After all, computers are the very definition of literal; they do not understand sarcasm or have intuition. They do exactly what humans tell them to, which is why they need simplified environments in the physical world and precise information in both the physical and digital worlds to function. But if that first step – of telling a computer exactly what to do – is not possible, the advantages humans possess could remain in place indefinitely.

Machine learning – The new frontier

What if machines could learn on their own? It would completely change what they can and cannot do, including in the field of work. Thanks to the confluence of several conditions, we may now be at this breakthrough point.

Figure 3

In our view, the three conditions that have allowed for the rise of machine learning are:



Source: Barclays Research

The rise of Big Data

The world creates massive amounts of data, for two reasons. First, economies are increasingly digitised. There are coffee shops in New York City where cash is no longer accepted – something that would have been unthinkable even 10 years ago. Every time we buy coffee with either a digital wallet or a credit card, a new data point is created. Cellphones, RFID readers, security cameras, digital signage and a million other things that create data now exist in the physical world.

Second, human behaviour has changed, with far more of our interactions moving from the physical to the online world. Every day, billions of people snap digital photos, send instant messages, post online and tweet. Market intelligence firm IDC estimated in 2014 that the total amount of data created in the world in 2013 was around 4.4 zettabytes.[5] One zettabyte is a trillion gigabytes, or 10^{21} bytes. To provide context, 200–250 songs of three to five minutes each can usually fit into one gigabyte of data. Now multiply that by a trillion.

IDC also estimated that the digital universe would double every two years for the next several years, reaching 44 zettabytes annually by 2020. In 2017, IDC updated its estimates; not only did its 2020 forecast seem to be on track, but the report estimated that the global datasphere would grow to 160 zettabytes by 2025.[6]

Admittedly, both of these reports were sponsored by large data storage companies (EMC in 2014 and Seagate in 2017) and there can be very significant errors in estimating something as amorphous as all data generated globally. But other sources, including Cisco's work on internet traffic growth and IBM estimating data created every minute, concur – global economies generate an enormous amount of data, and it continues to grow at an exponential pace.[7]

5 https://www.emc.com/leadership/digital-universe/2014iview/executive-summary.htm

6 https://www.seagate.com/files/www-content/our-story/trends/files/Seagate-WP-DataAge2025-March-2017.pdf

7 https://www.cisco.com/c/en/us/solutions/collateral/service-provider/visual-networking-index-vni/vni-hyperconnectivity-wp.html

Figure 4

Technology is getting smarter - and cheaper

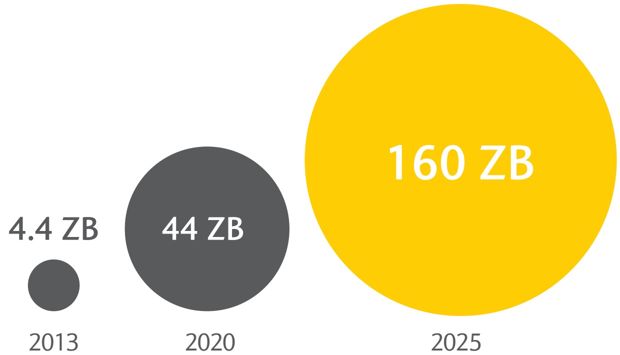
In recent years, three conditions have converged to make technologies such as Artificial Intelligence and robotics more commercially viable.

Data is predicted to double every two years

Almost everything we do creates data, from global imports and buying coffee to medical implants and social media.

Source: IDC, 2017

Size of the global datasphere



1 zettabyte = 1 trillion gigabytes

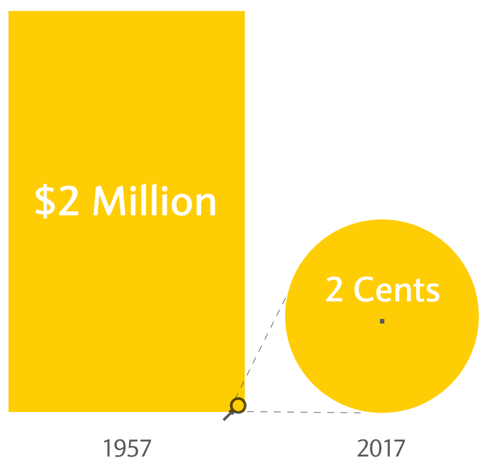
200-250 average-length songs usually equal one gigabyte of data.

Data storage costs have plummeted

Data processing and storage capacity now seem limitless, while costs continue to drop. And more data leads to faster, smarter innovation.

Source: Mearian, Lucas, Computerworld 2017

Cost to store 1 GB of data

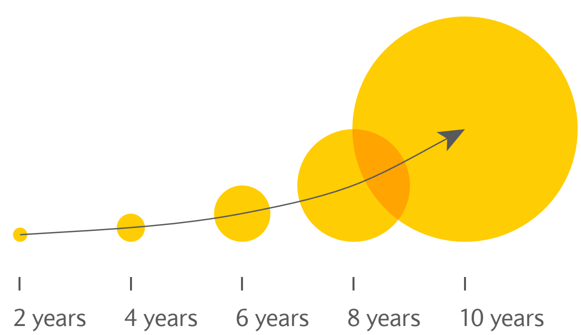


Transistors on integrated circuits nearly double every 24 months

With cheaper computing power, it's now affordable to run simulations using vast quantities of data. This means artificial neural nets can extract more rules and patterns, greatly improving machine learning.

Source: Moore's Law

Growth in computing power over time



Decline in data storage costs

But if the world economy is creating data at this dizzying pace, what does one do with it? Is there a point to trying to catch the Niagara Falls in a bucket? As it turns out, yes, there is. Not all data are useful and need to be stored. More importantly, even as data generation has exploded upwards, data storage costs have plummeted. Computerworld reported in 2017 that data storage costs have gone down 41% per year for the past 60 years.[8] A gigabyte of capacity cost $2 million 52 years ago (not adjusted for inflation). Now it costs two cents. The collapse in data storage costs has allowed companies to store increasingly large amounts of data, just as there are far more data to store.

Continued decline in computing costs

In 1965, Intel co-founder Gordon Moore observed that the number of transistors on integrated circuits doubled approximately every two years and forecast that this could continue for at least another decade.[9] The prediction proved uncannily accurate for several decades and became known as Moore's Law.

It is a remarkable statistic that has no parallel in other industries. Planes do not double in speed and cars do not consume half as much oil every two years. Current Intel CEO Brian Krzanich said in 2015 that the pace of advancement had now slowed to two and a half years instead of two, which is still incredible.[10] At some point, the laws of natural physics might slow the pace of improvements, but that day still appears distant.

Meanwhile, the cost of computing power is now trillions of times cheaper than it was a few decades ago, thanks to the exponential power of Moore's Law.

The technology behind machine learning – artificial neural nets – is based on neural networks and has been around for decades. What is different now is that computing power is cheap enough for companies and economies to run computer simulations of how billions of neurons behave, allowing machines to extract rules and patterns from vast quantities of data.

In other words, recent developments in machine learning are less about the development of a completely new technology and more about its becoming commercially viable while being able to draw on vast quantities of data. You need the existence of Big Data, the ability to capture and store it, and enough cheap computing power to make sense of it. For the first time, all three are available.

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8 https://www.computerworld.com/article/3182207/data-storage/cw50-data-storage-goes-from-1m-to-2-cents-per-gigabyte.html

9 The implication was that chip performance would double every two years if costs were unchanged. Or put another way, computing costs would halve every couple of years.

10 http://fortune.com/2015/07/17/moores-law-irrelevant/

Machines doing what humans do

So what exactly is involved in machine learning? Computers are great at following rules, written in programmes. If a credit card borrower has a FICO score below 600, the interest rate on his credit card should be at a certain level – that's a rule a computer can follow. Add in more rules and you get an algorithm – still no problem as long as the computer's existing code is set up to handle it.

But machine learning represents a fundamental change. It is a subset of the much-abused term 'Artificial Intelligence' and is grounded in statistics and mathematical optimisation. The computer is fed vast data sets and a few general parameters to point it in the right direction. Then, the machine executes simulations of how biological neurons behave, uses that to recognise recurring sequences in the data, and writes its own rules.

Suddenly, it is no longer limited to applying algorithms that a human wrote; the machine is designing its own.

Machine learning has vast applications, especially when coupled with other innovations

Machine learning algos not only recognise, but also analyse patterns in data and allow the machine to respond in ways that have not been specifically programmed. The algorithms keep iterating over data sets, allowing the machine to keep learning and to spot new patterns. And once a machine spots a new pattern, it can instantly be 'learned' by other machines linked to the same platform. For example, Tesla CEO Elon Musk has emphasised that "The whole Tesla fleet operates as a network. When one car learns something, they all learn it."[11]

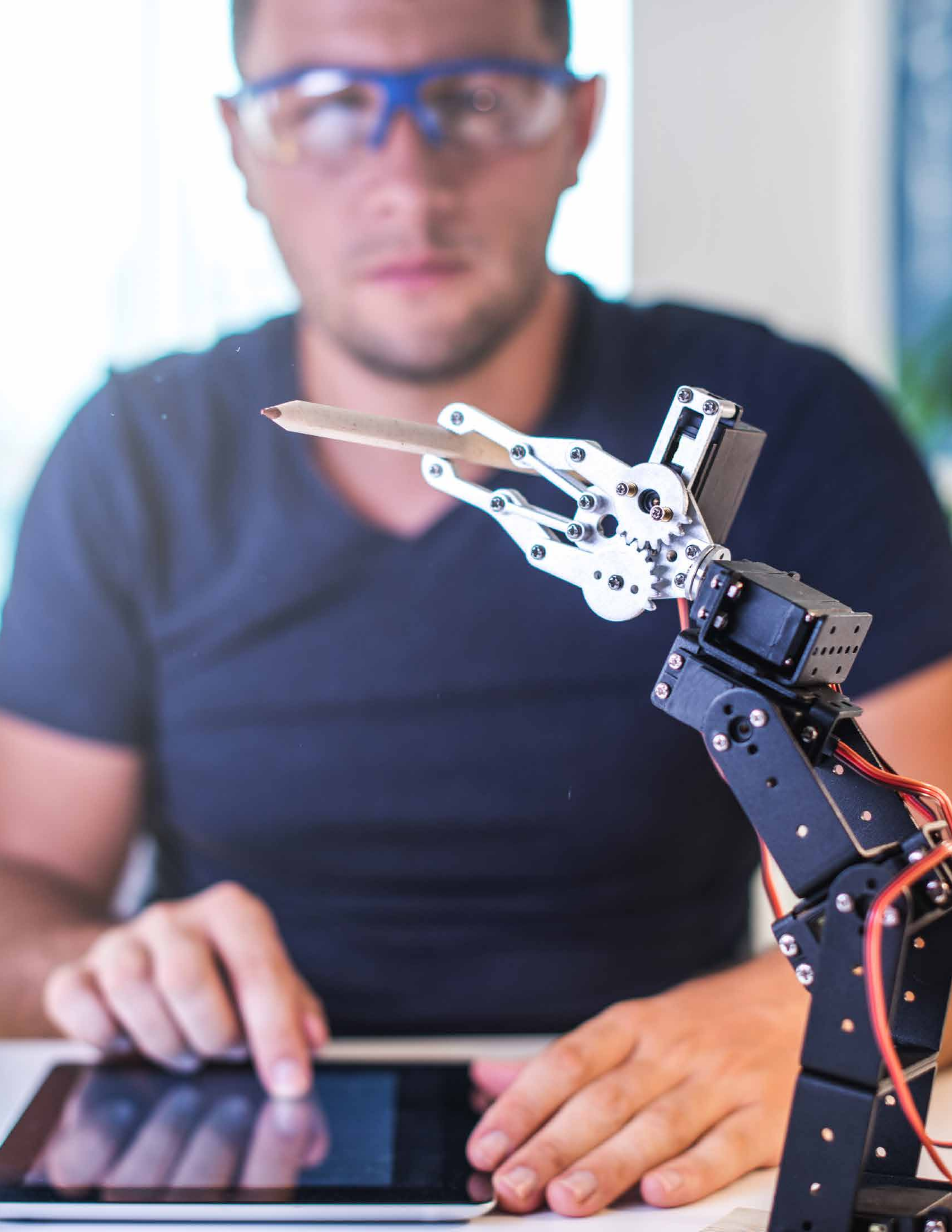
In addition, the bigger the data set, and the more time the algos spend with it, the more they end up learning from their mistakes and getting better. One place where this improvement is immediately apparent is in spam email detection. Spam rates across every major email provider have gone down sharply in recent years as machines become better at 'learning' what is spam and what isn't.

11 http://fortune.com/2015/10/16/how-tesla-autopilot-learns/

Lessons from the net

One current leader in machine learning usage is online retail, where predictive analytics are used for product recommendations. The 'frequently bought together' option on an ecommerce website (such as Amazon) pushes buyers into spending more than they planned to when they logged on. The parameter that the machine is looking to optimise for is to increase the value of the virtual shopping cart. It does so by finding patterns in previous orders, what products on the Amazon website the customer seems interested in, whether this customer's profile fits a certain subset of customers, when the purchases happen, the average order value, the frequency of orders, and past ratings or reviews.

Similarly, streaming video services such as Netflix seek to maximise the amount of time a user spends using the service. Netflix's recommendation engine looks at what users are watching, what they are searching for and whether there are similarities to other users' patterns. If so, it recommends shows and movies that other similar users have shown interest in. All the while, the machine learning algos absorb new data, learn from it and improve their recommendations.



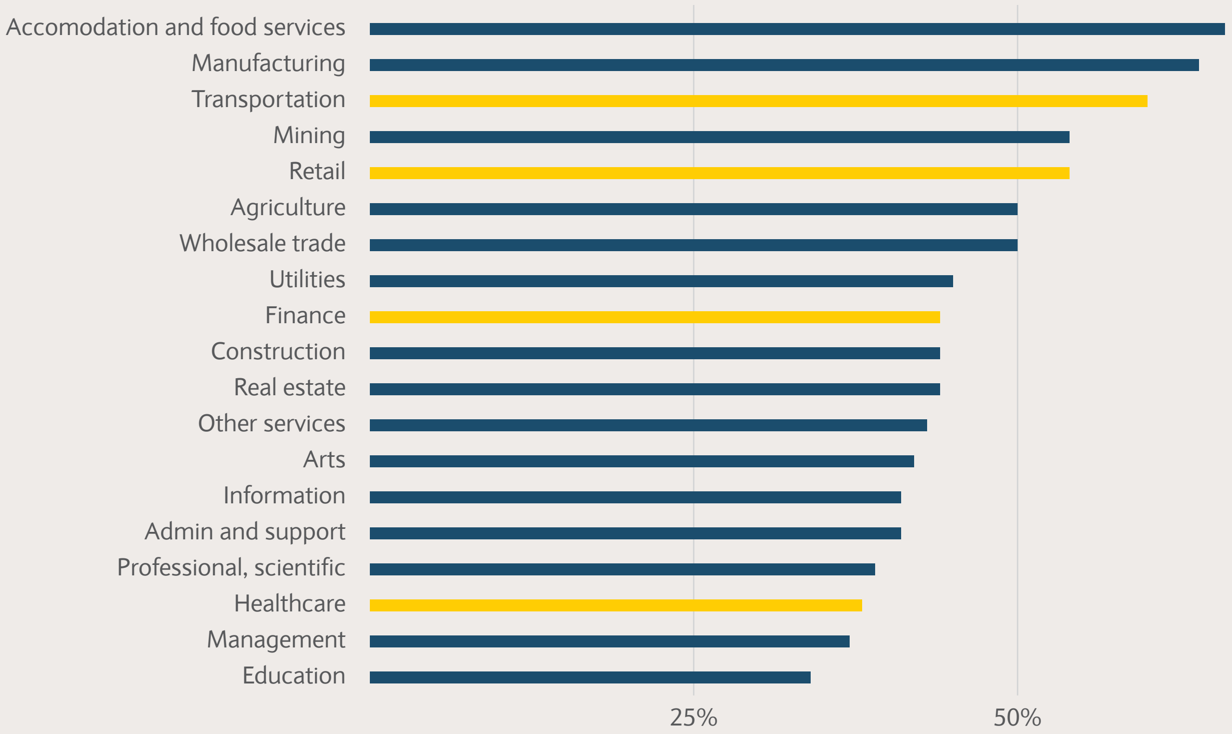
Automation examined: Four sectors as case studies

Machine learning applications across industries are wide ranging. In 2016-2017, think tank MGI broke down hundreds of industries into thousands of tasks.[12] It found that with existing levels of machine learning, automation could end up playing a significant role in nearly half of all activities in the modern economy. As with the development of artificial neural networks, the constraints to automation are not technological. Instead, the big hurdles are factors such as cost, changes in consumer behaviour and regulatory intervention.

In this section, we take a closer look at automation in four sectors: Finance, healthcare, retail and transportation.

Figure 5

Automation potential across sectors



Source: McKinsey Global Institute

12 McKinsey Global Institute, *A future that works*, January 2017

Finance: Ripe for automation

Where it all began

With the first installation of the humble automated teller machine (ATM) in 1967. It took over routine tasks from human tellers, such as handling cash and providing account information.

Innovations to date

Robotic process automation

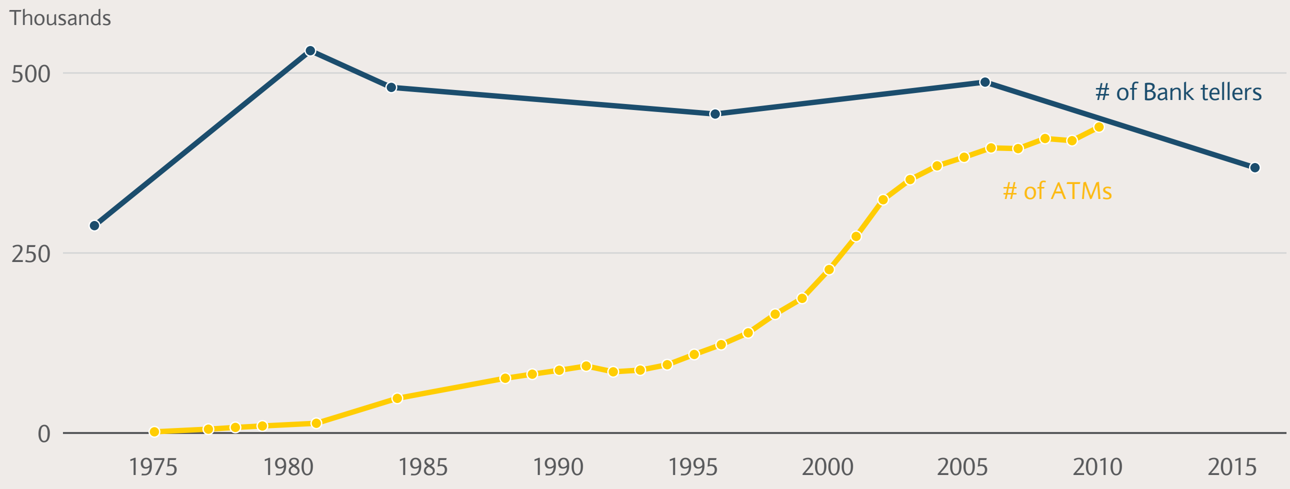
Much of the more recent automation in finance has been through robotic process automation (RPA) – essentially removing repetitive tasks from humans and allowing employees to focus on their 'human strengths', including emotional intelligence, reasoning, judgment, creativity and so on.[13] Repetitive tasks can be codified and do not require higher order cognitive functions to complete. In financial services, RPA tasks are typically found in middle- and back-office functions in operations, information technology, finance, risk management and human resources. Return on investment from an RPA implementation is high and is found to vary from 30% to 200% in the first year.[14]

Retail banking

Freeing up staff to deal with more complex issues is one of the greatest effects ATMs have had on retail banking. As they proliferated in the 1990s (Figure 6), the average number of tellers per bank branch fell from 21 to 13.[15] However, the total number of tellers increased initially as banks opened more branches and tellers focused on more complex transactions and relationship management. The number of bank tellers as a share of total employment increased nearly 1.5 times between 1972 and 1980.[16]

Figure 6

Bank teller employment initially increased with ATM adoption



Source: BLS, BIS, Haver Analytics, Barclays Research

13 McKinsey & Company, "The next acronym you need to know about: RPA (robotic process automation)," 2016

14 McKinsey Global Institute, *A future that works*, January 2017

15 Bessen (2015), *How Computer Automation Affects Occupations: Technology, Jobs and Skills*, Boston University School of Law, Law & Economics Working Paper

16 Carol Leon, "Occupational winners and losers: who they were during 1972-80," Bureau of Labor Statistics, 1982

Over time, however, the widespread adoption of ATM technology and its broadening functionality slowed this trend, and tellers as a share of overall employment returned to early 1970 levels by the mid-1990s and has continued lower until the present day.

Insurance

The industry is likely to be disproportionately affected by wider RPA adoption. McKinsey found that average numbers of employees in issuance functions were down 10% in Life and 7% in Property and Casualty insurance companies between 2010 and 2014. It estimates that automation could lead to a 25% decline in full-time equivalent (FTE) – hours worked per employee – by 2025.[17]

Mortgages

Automation could significantly shorten the current 37 days it takes for the average US mortgage application to be approved, of which two to three weeks are spent collecting and processing data.[18] It will reduce labour costs and applicant dropout rates of about 30%. McKinsey estimates that the run rate benefit of automating mortgage processing is about 11 times the cost of automation.

Future innovations

Intelligent process automation (IPA)

More sophisticated algorithms, IPAs build on RPAs by including process management tools that better integrate tasks performed by robot and human workers, machine learning techniques that provide quicker insights and natural language processing that allows seamless integration between humans and technology.

- **Cognitive agents** in financial services answer product-related questions and pricing quotes. IBM estimates that the average person makes 65 customer service calls in one year, amounting to nearly $1.3trn of costs for businesses.[19] Cognitive agents are improving at answering client queries and are also venturing into sales functions.
- **Cognitive tools** are assisting regulatory compliance efforts by automating internal fraud investigations, anti-money laundering identification processes and compliance in customer conversations (e.g., IBM's Regulatory Compliance Analytics with Watson) among other tasks. In investment banking, intelligent software can be found in transaction analysis (e.g., Kensho) and disclosure data (e.g., iDisclose).
- **Robo advisors** are slowly becoming more pervasive in investment advisory and currently manage billions of dollars worth of assets. S&P estimates that assets under management (AUM) by robo advisors increased from $98bn in 2016 to about $143bn in 2017 and predicts AUM to reach $450bn in 2021.[20]

Impact of automation

- We estimate that about 30% of the 5.7 million finance and insurance sector jobs (based on BLS data) are fully automatable (with >95% automation probability using metrics developed by Frey and Osborne), but there is also a sizeable nearly 20% share that have extremely low levels of automation potential (<5% automation probability).[21]
- The labour-saving aspects of automation in finance will likely be offset to some extent by the emergence of new products and focus on higher value-added activities. The relatively high levels of education in finance and insurance overall (46% of the sector's employment has a bachelor's degree or higher) suggest a higher potential for redeploying workers in alternative functions.

17 McKinsey & Company, *Insurance on the threshold of digitization: Implications for the life and P&C workforce*, December 2015

18 McKinsey Global Institute, *A future that works*, January 2017

19 https://www.ibm.com/blogs/watson/2017/10/how-chatbots-reduce-customer-service-costs-by-30-percent/

20 https://www.spglobal.com/our-insights/US-Digital-Adviser-Forecast-AUM-To-Surpass-450B-By-2021.html

21 Carl Benedikt Frey and Michael Osborne, *The future of employment: How susceptible are jobs to computerization*, September 2013

Healthcare: Wide array of applications

Where it all began

Surgical robots. In 1992, the ROBODOC system assisted a surgeon in a hip replacement procedure.

Innovations to date

Healthcare has long been viewed as fertile ground for automation in clinical decision support, patient monitoring and coaching, management of healthcare systems and indirectly in surgery/patient care. Since that first hip replacement in 1992, the ROBODOC system has been extended to other orthopedic surgeries such as knee replacements. The standard of care in laparoscopic surgeries is a robot known as the Da Vinci system, first marketed for minimally invasive heart bypass surgeries in 2000.[22]

The widespread adoption of automation, however, remains slow, largely as a result of social barriers to gaining trust from patients and doctors, not to mention the regulatory, policy and commercial obstacles that have prevented access to data, which has been key to surges in automation in other sectors.

Future innovations

Demographics and rising incomes imply more demand for healthcare. Health spending is expected to rise 3% per capita on an annualised basis globally.[23] At the same time, the healthcare sector is likely to have a shortage of doctors and longer patient wait times – all pointing to the need for more automation. New technologies such as wearable devices, cheaper sensor technology, lower cost of storage, and developments in cognitive computing methods and robotics are increasing automation adoption in this sector.

- Wearable devices would be able to assist in **patient monitoring** in hospital, but also for those with chronic conditions and those seeking preventive healthcare advice. Sensor technology has had a dramatic reduction in costs. For example, sequencing the human genome cost roughly $2.7 billion in 1991, but has since fallen to $300,000 in 2006, $1,000 in 2014 and $200 in 2017.[24] This industry is particularly dependent on data storage costs, which have fallen substantially (Figure 4).
- **Clinical decision support** is an area in which the automated reasoning process is able to augment the human dimension of patient care. For example, in radiology, neural networks are already analysing X-rays, CT scans and MRI imagery and are likely to complement doctors' decision-making. Huge data sets are available for cognitive computing techniques to mine, including doctor's notes, images, pathology reports and genome mapping and the ability to cross-reference this with research studies, medical books, etc.

22 Stanford University, "One hundred year study on artificial intelligence," 2016

23 Dieleman, Joseph, et al, "Future and potential spending on health 2015–40: development assistance for health, and government, prepaid private, and out-of-pocket health spending in 184 countries", *The Lancet*, Volume 389, Issue 10083, 2005–2030

24 https://www.genome.gov/sequencingcostsdata/

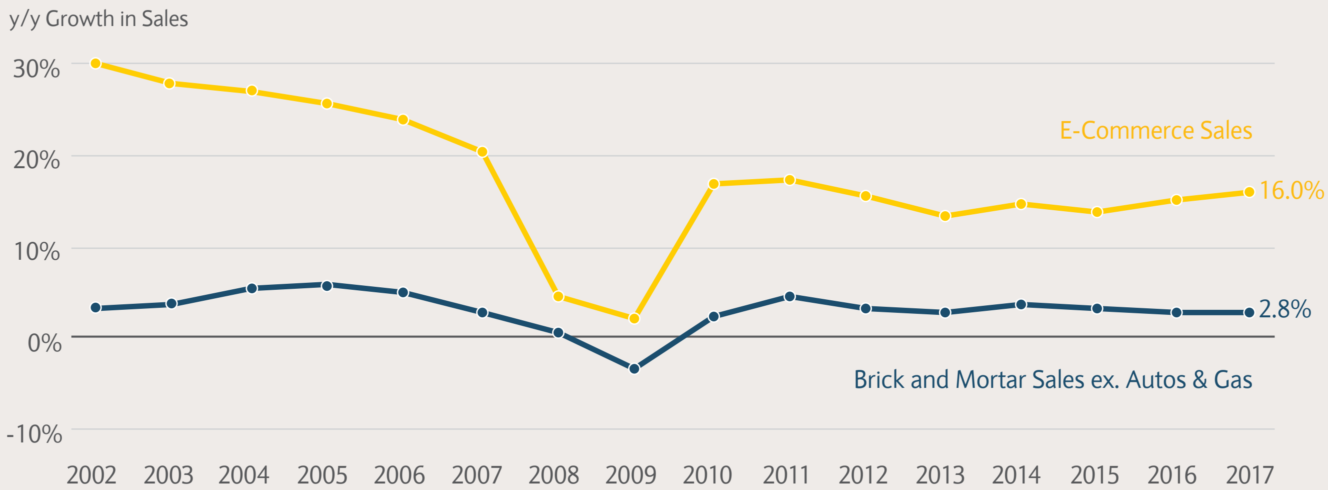
- **Personal health monitoring** has become more plausible, particularly given the dramatic reduction in sensor technology costs, the lower storage costs of data and powerful machine learning algorithms. For virtual health advisors of the future to be able to provide individual advice, they will need to collect hundreds of data points from millions of people. Social networks for sharing health data (e.g., ShareCare) are a starting point to gain insights on population-scale characteristics to produce individual analytics and recommendations.
- **Hospital and healthcare systems management** can also benefit from automation. Machines can take on routine activities including patient registration, checkout, the dispensing of prescriptions, billing and administrative activities.

Impact of automation

- The potential for automation is lower for healthcare professionals who interact with patients and deal with non-routine tasks. Only 30% of nursing activities can be automated; tasks such as administering non-IV medicines, delivering food, data collection, anesthesia and radiology are fully automatable, however. As such, automation is likely to complement healthcare professionals and enhance industry productivity.
- Across the industry in the US, we estimate that only about 10% of the nearly 20 million jobs are fully automatable, whereas we find that 30% of healthcare jobs actually have very low levels of automation potential (based on Frey and Osborne).

Figure 7

E-Commerce's Dramatic Growth Is Starting to Pressure Brick and Mortar's



Source: Bloomberg

Retail: The battle for supremacy

Bricks and mortar retail has faced a ferociously competitive landscape in recent years with the onslaught from e-commerce. Although the majority of retail business is still largely offline, online market share reached just shy of 10% of total US retail sales in 2017. If the difference in relative growth rates (Figure 7) continues, gains in e-commerce market share are likely soon to be large enough to drive the absolute growth of offline retail to negative numbers. At the same time, retailers are under tremendous cost pressure from wage inflation, with most minimum/starting salaries now $15 per hour. The result has been twofold: retailers are investing in more automation and technology, and the pace of bankruptcies and store closings has accelerated.

The stakes for the broader economy cannot be overstated, with the retail sector accounting for about 6% of US GDP and about 10% of overall employment. Of course, as with all such structural changes, there is a ray of light: significant growth in jobs in distribution centers and delivery that support online sales have been offsetting roughly one-third of the recent losses for retail employment.[25]

Where it all began

An early attempt at soft automation was the introduction of barcode scanners in the 1930s, although the first scan only took place in 1974 at a Marsh supermarket in Troy, Ohio. Although they are a labour-saving technology, scanners have also allowed supermarkets to measure worker productivity, carry more products, run better promotions strategies and analyse customer behaviours. Basker (2012) estimates that early scanners increased store productivity by 4.5%, with larger effects in stores that carry more packaged products with barcodes.[26] Basker and Simcoe (2017) showed that the adoption of scanners correlated with increased employment for upstream manufacturers and an increase in international trade flows, particularly imports, as inventory management improved.[27]

Innovations to date

RFID tagging technology

While it has also been around for a very long time (the first military uses were during World War II, and the first commercial patents were awarded in the 1970s), it became a reality only in the late 1990s. RFID tagging allows retailers to compete with ecommerce platforms by enabling frequent inventory counts and saving labour costs in the auditing process.[28] Combined with mobile technology and algorithms for delivering personalised coupons, this can help stores target customers more efficiently.

Self-checkout kiosks

Its origins can be tracked back to the development of the ATM and interactive voice response in the 1970s. The first commercial use of self-checkout kiosks had to wait until the early 1990s, with widespread adoption over the next decade. Self-checkout machines allow retailers to save on labour and optimise floor space utilisation while delivering a more convenient and rapid checkout experience for consumers.

Future innovations

Automation can tackle the typical frictions that customers have cited for shopping in store, such as crowds, long checkout times, uncertain inventory, etc. (Figure 8).[29]

25 *US Economics and Credit Strategy: Technology-based change leaves retail looking overextended*, 7 June 2017

26 Basker, Emek. “Raising the barcode scanner: Technology and productivity in the retail sector.” *American Economic Journal: Applied Economics* 4, no. 3 (2012): 1-27

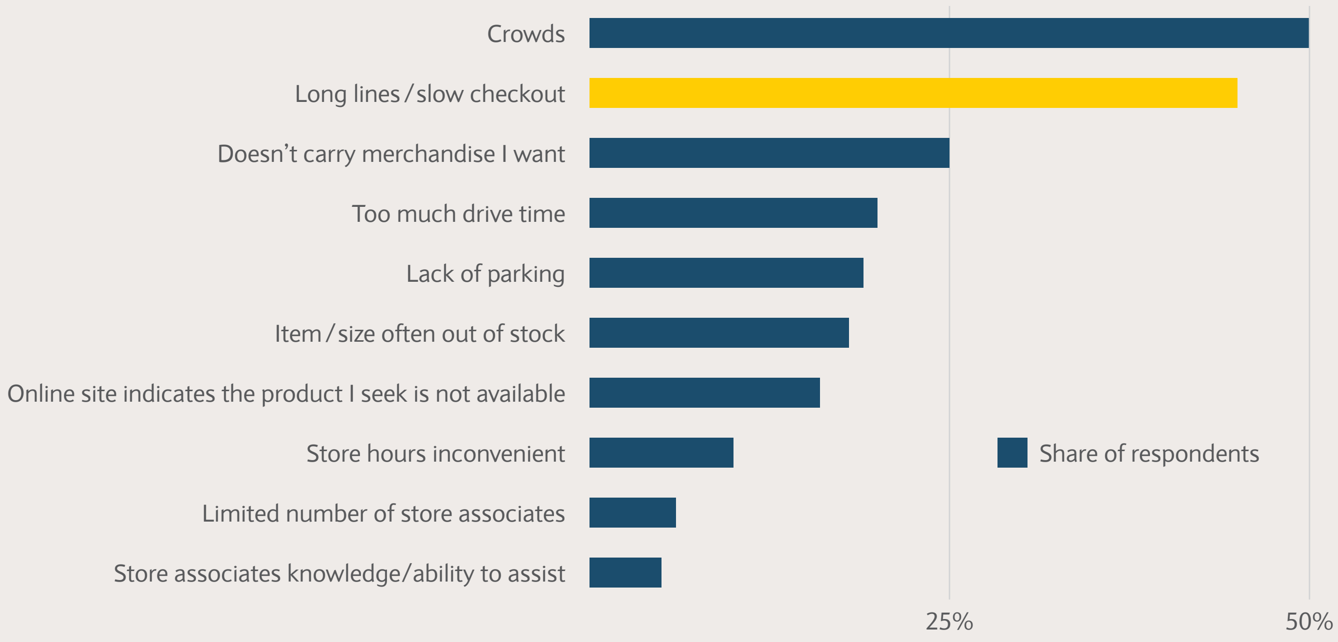
27 Basker, Emek, and Timothy Simcoe. *Upstream, Downstream: Diffusion and Impacts of the Universal Product Code.* No. w24040. National Bureau of Economic Research, 2017.

28 Cornerstone Capital Group, *Retail automation: Stranded workers? Opportunities and risks for labor and automation*, May 2017

29 Cornerstone Capital Group, *Retail automation: Stranded workers? Opportunities and risks for labor and automation*, May 2017

Figure 8

Barriers to shopping in stores



Source: Deloitte Annual Holiday Survey, 2016, Cornerstone Capital Group

The World Economic Forum estimates that 30%–50% of the retail sector is at risk of automation and potentially 15% of retail stores are likely to close.[30] It identified eight new technologies as driving disruption in retail: Internet of Things (IoT), autonomous vehicles/drones, machine learning, robotics, digital traceability, 3D printing, augmented and virtual reality, and blockchain. We discuss the specific applications to retail below.

- Self-checkout technology is maturing into the **automated checkout** experience in Amazon's Go store. The technology automatically detects which products are taken or returned to store shelves, keeps track in a virtual cart and bills the customer's Amazon cart on exiting the store. Machine learning and sensor fusion is coming of age in consumer retail.
- For consumers, digital kiosks can act as **virtual sales associates,** providing information and reviews and making suggestions. The implementation of digital tags can help guide consumers around the store and can be customised based on their preferences.
- **Robotic automation** is also being envisioned. Walmart has patented motorised units to help move items around the store; scan, retrieve and deliver products; conduct inventory checks; and even engage in store maintenance.

Impact of automation

- The two largest job roles in retail, cashiers and sales associates, account for about 45% of industry employment and have probabilities of automation of 97% and 92%, respectively (based on Frey and Osborne (2013)).
- We estimate that about 60% of the 15.7 million people in the retail sector (totalling more than 7% of the US labour force) work in jobs with above 90% automatability, whereas only 5% are employed in jobs with very low probabilities of automation. The displacement of labour as a result of automation is likely to be especially problematic because less than 20% of workers in highly automatable jobs have Bachelors or advanced degrees.

30 World Economic Forum, *Shaping the future of retail for consumer industries*, 2017

Transportation: Driving into the future

Where it all began

Urban railways have operated under automated control since the 1960s (e.g., trains have been running automatically between stations on London's Victoria line since 1967, with the driver responsible only for door closing and emergency situations). Commercial aviation has been highly automated since at least the early 1980s, with pilots responsible for flying for a few minutes during takeoff and landing. These early forays into automation were possible largely because of the routine nature of the tasks involved and the substantially smaller number of environmental factors involved in rail and air transport.

Innovations to date

Driver assistance

Only a decade ago, navigating a car through traffic was not considered automatable. But the rapid adoption of driver assistance has led it to be incorporated even in low-priced vehicles. Current advances remain short of full automation in driving vehicles, but partial automation is now a reality in luxury vehicles, and high levels of automation are likely to be incorporated within the next five years. Full automation is still a 10-year prospect, according to a study conducted by McKinsey.[31] The main barriers are:

- **Reliable hardware systems**: The initial challenges focus on the hardware to collect and process the vast amounts of data to read surrounding environments and other vehicles, identify the car's exact location and compare it against available mapping information. Hybrid combinations of radar and camera (Lidar) systems and GPS localisation and onboard cameras are increasing. Sensor technology and computational power appear to be approaching levels needed to solve the hardware requirements of autonomous road navigation in the not-too-distant future.

- **Software** remains the biggest stumbling block, making it difficult to analyse surrounding objects and situations, make decisions, establish fail-safe mechanisms, and conduct robust testing and validation. Artificial Intelligence has led to some advances. Complemented by rules-based decision-making in a hybrid approach, neural networks can be trained to handle the wide range of driving situations. But engineers need to ensure adequate safeguards in the event of emergencies and malfunctions.

- **Testing and validation techniques** may be the most daunting challenge in generating high levels of confidence in autonomous vehicles. Studies indicate that 275 million miles of driving would be required to demonstrate a failure rate of 1.09 fatalities per 100 million miles (the 2013 US human fatality rate) with a 95% confidence level. That equates to roughly 100 autonomous vehicles driving 24 hours a day, 365 days per year for more than 10 years to get the requisite number of miles.[32]

Future innovations

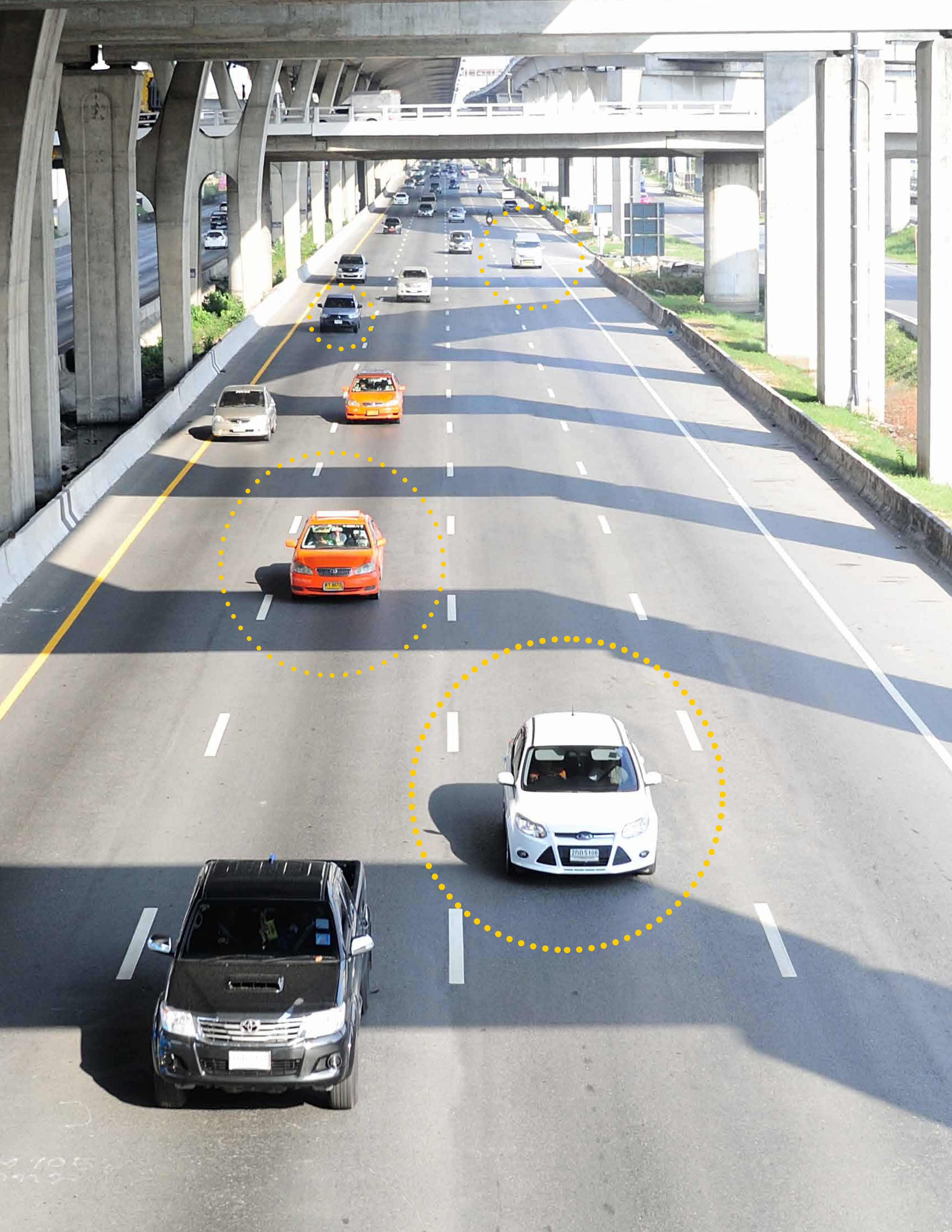
- **Self-driving personal cars**: Initial use will likely be in specific geographies using geofencing, with additional optimisation and refinement leading to broadening of geofenced regions.

- **Long-haul trucking** may see earlier adoption of automation because a large share of trucking is on highways, where there are no pedestrians and intersections. Additionally, automation costs are a smaller share of vehicle costs for trucks than for personal cars. Truck drivers could soon drive to the highway and input a distant point into the onboard computer before hopping out and having the truck eventually picked up by another driver to navigate the remaining distance.[33]

31 McKinsey & Company, "Self driving car technology: When will the robots hit the road?" May 2017

32 Rand Corporation, *How many miles of driving would it take to demonstrate autonomous vehicle reliability*, 2016

33 Kennedy, Joe, "How regulatory reform can advance automation in freight transportation sector," ITIF, June 2017

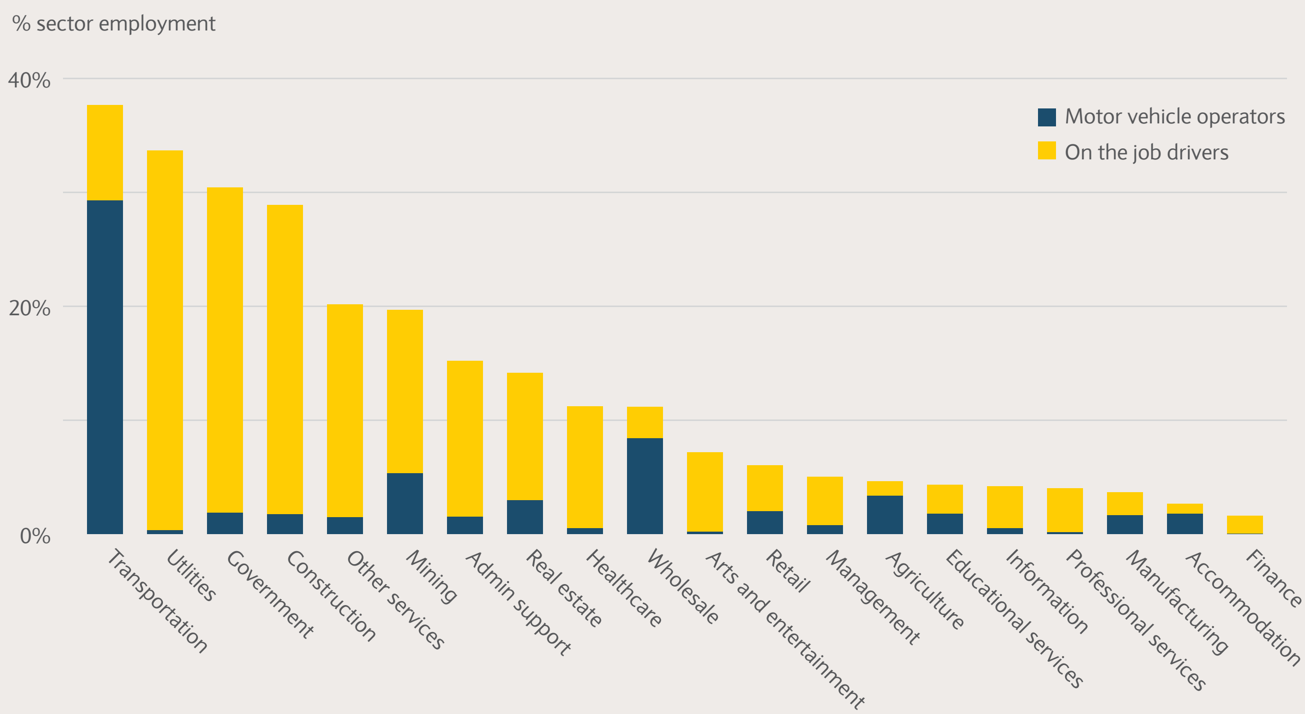


Impact of automation

- Self-driving vehicles have the potential to have a large effect not only on the transportation sector, but also on other industries that rely on driving to a high degree.[34] Roughly 3.9 million workers in the US directly operate motor vehicles, including 1.7 million truck drivers. A further 11.9 million workers deliver services that require vehicles. Together, these represent roughly 11% of the total workforce (Figure 9). From a capital stock perspective, motor vehicles represent roughly 12% of the total stock of equipment across all business sectors (based on Bureau of Economic Analysis data). Business investment in motor vehicles ($335bn per year) represents a little over half of the total final domestic sales.
- Autonomous vehicles' impact depends on whether it is labour saving or productivity enhancing. For the direct motor vehicle operators, it is likely largely to have labour-saving effects. Motor vehicle operators tend to score lower on knowledge outside of their narrow field, have limited cross-functional skills, have lower education levels and so on, and automation is likely to increase unemployment levels among these workers.
- For sectors of the economy that employ individuals who use motor vehicles to deliver other services (e.g., security, electricians, mechanics of all sorts), autonomous vehicles are likely to benefit by providing greater productivity, such as the ability to focus on tasks instead of driving, as well as better working conditions, possibly including a reduction in road injuries and deaths.

Figure 9

Driving-related jobs by industry



Source: Bureau of Labor Statistics, Occupational Employment Statistics, 2015

34 US Department of Commerce, "The employment impact of autonomous vehicles," 2017

Will technology take away our jobs?

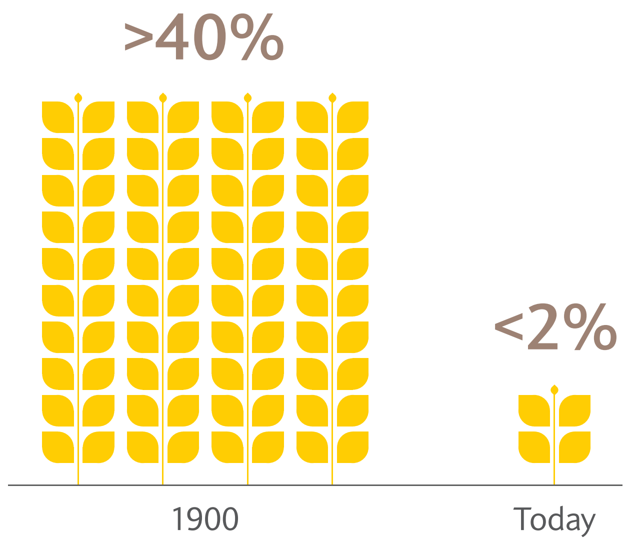
Machine learning allows machines constantly to learn and improve, developing skills in areas that have historically been the domain of humans. Fears that technology will wipe out jobs do come up periodically, and they are surfacing again.

In 2013, Carl Frey and Michael Osborne, co-directors of the Oxford Martin Programme on Technology and Employment at the University of Oxford, wrote that as much as 47% of all US employment was at risk from automation. And in 2015, the Bank of England warned that as many as 15 million jobs in the UK and 80 million in the US could be at risk from automation and machine learning.[35]

On the other hand, despite all the excitement over recent technological developments and related fears about the impact on workers, the US is close to all-time lows on the jobless rate at the time of publication (at 4.1%). The same is true of most other major economies. These low rates are hardly symptomatic of a world where machine learning is leaving the labour force jobless, at least for now.

Figure 10

Percentage of US population engaged in agriculture



Source: Cenedella, Marc. *Business Insider*. 2010.

The ‘lump of jobs’ fallacy

Most mainstream economists now acknowledge the ‘lump of jobs’ fallacy and agree that there is no such thing as a fixed amount of work. If technology automates away existing jobs, new jobs of a different nature eventually take their place. The transition is not smooth and can wreak havoc on individual communities (as seen in the death of ‘factory towns’ across the United States). But eventually, new jobs usually take the place of the old. At the turn of the last century, over 40% of the US population was engaged in agriculture. Now the number is below 2%, even as the vast majority of the population remains gainfully employed (Figure 10).

More tech innovations, more demand, fewer job losses

There are a few reasons why technology hasn’t ended up making jobs scarce over the years. First, technological gains often change the demand for a product, mitigating job losses in that specific sector. Consider the construction sector, which a century ago used wheelbarrows and hand shovels as the primary means of moving earth. The development of bucket wheel excavators and other earth-moving machines completely changed the nature of work in that sector. But as technological gains made constructing buildings more affordable, it also increased demand. A five-story apartment complex might have been the talk of the town in the days before Caterpillar. But suddenly, skyscrapers were not only possible, but probable. The quality of housing stock improved, more focus shifted to areas such as designing the interiors, and per square foot consumption of real estate went up sharply. A hundred years later, construction remains one of the biggest employers in most developed countries.

35 https://www.theguardian.com/business/2015/nov/12/robots-threaten-low-paid-jobs-says-bank-of-england-chief-economist

This phenomenon – technological development sharply increasing demand for a product – has been observed across the centuries. Rapid productivity growth as a result of technological advancement often generates price declines, which in turn pushes up demand. For example, job creation in the British textile industry went up sharply between 1810–1840, decades after the introduction of the power loom, because demand for textiles exploded as they became cheaper.

This pattern does not hold in every case, of course. There is only so much demand per capita for agricultural products, regardless of falling costs. A family of four can go from one personal tablet per family to two (or more) devices per person as costs per unit fall, but they are unlikely to eat eight times as much, no matter how cheap food becomes.

Figure 11

Technology creates new jobs and earning opportunities

Source: https://www.apple.com/newsroom/2018/01/app-store-kicks-off-2018-with-record-breaking-holiday-season/

Technology creates new industries, which in turn create more new industries, and so on

As new technologies make existing ones obsolete, they typically drive new job creation in related sectors. Take, for example, the advent of the modern automobile, which decimated industries that supported the horse-and-buggy system, which was the main mode of conveyance until then.

Farriers, companies that made bridle reins and horse saddles, companies that kept stables across the country, the army of people who swept up horse dung from city streets – they all found themselves suddenly at a loss. But in their place, new industries arose, with more job creation.

Workers in Detroit's assembly lines, car mechanics, garages, petrol stations – these were all job spin-offs of the new technology. And in some cases, the second-order effects were more important for job creation, as new technology spurred complementary developments. For example, a national highway system would have made little sense in the era of the horse carriage. But it very much did make sense with the arrival of the internal combustion engine, which led to households traveling far more than they previously would have, which in turn led to the development of roadside motels and restaurants. Highways, in turn, helped facilitate the development of the long-haul trucking industry, the largest non-college employer in the United States.

To date, technology has tended to create more jobs than it destroys. MGI estimates that 15.8 million jobs were created in net terms with the adoption of computer technology since 1980.[36] Take the job of 'app developer', which was not a job definition 20 years ago. Now there are millions of such developers worldwide. In January 2018, Apple reported that developers had earned $86 billion since its App Store launched in July 2008 (Figure 11).[37]

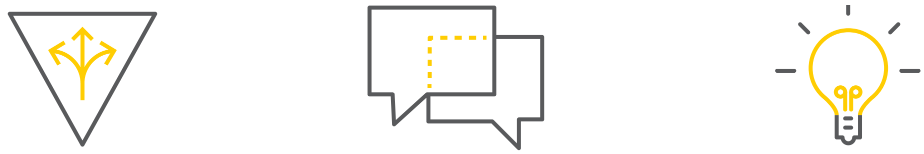
Thanks to technological progress, many new jobs are created in other sectors, particularly service sectors. As the workweek has declined due to productivity increases, people now consume far more services than they have historically. And that leads to new job creation.

36 McKinsey Global Institute, "A future that works," January 2017

37 https://www.apple.com/newsroom/2018/01/app-store-kicks-off-2018-with-record-breaking-holiday-season/

Figure 12

Tomorrow's jobs will likely be in areas where humans retain an advantage over machines



Highly unpredictable circumstances

Think plumbers or lawyers, where the ability to adapt on the spot is crucial.

Complex personal relationships

For example, relationship managers, doctors and nurses – where trust, comfort and connection are important.

Real creativity

Machines have yet to replicate personal expression, emotion, opinion and imagination the way an artist or scientist does.

Source: Martin Ford

What does the past tell us about the future?

Of course, just because human ingenuity has in the past always found a way to mitigate the impact of job-killing technology does not guarantee that the same will hold true in the future.

But even these categories of jobs might be theoretically vulnerable. For example, surgeons already use robots widely in surgeries; micro-robots can perform surgeries at microscopic levels (still under the direction of a human) that surgeons cannot manually perform. Human judgment is still essential, but might become less so with the development of machine learning platforms in the medical field.

With the development of machine vision, machines could also be better equipped to make medical diagnoses. One of the world's top hospitals, Memorial Sloan Kettering, is partnering with IBM's Watson Oncology to identify individualised, evidence-based treatment options for cancer patients.[38]

This trend is spreading in other areas as well. AI has been involved in creating a successful Europop album and another has beaten the human world champion in the Chinese game of Go (a game with an infinitely larger number of moves than chess, where human intuition was considered a major advantage over machines).[39] As such, it is not out of the realm of possibility that machines might someday write an award-winning novel or create an original art masterpiece.

But in our view, such possibilities are still decades away, if they ever do occur. Much of the impact of technology in an economy depends not just on what is technically feasible, but also on how human attitudes evolve. It is difficult (at least for the foreseeable future) to imagine a parent being comfortable with their small baby being attended to only by a robot without any human supervision. Similarly, patients are still likely to be sceptical of having life-or-death surgeries performed on them by machines without an attending surgeon (Figure 12).

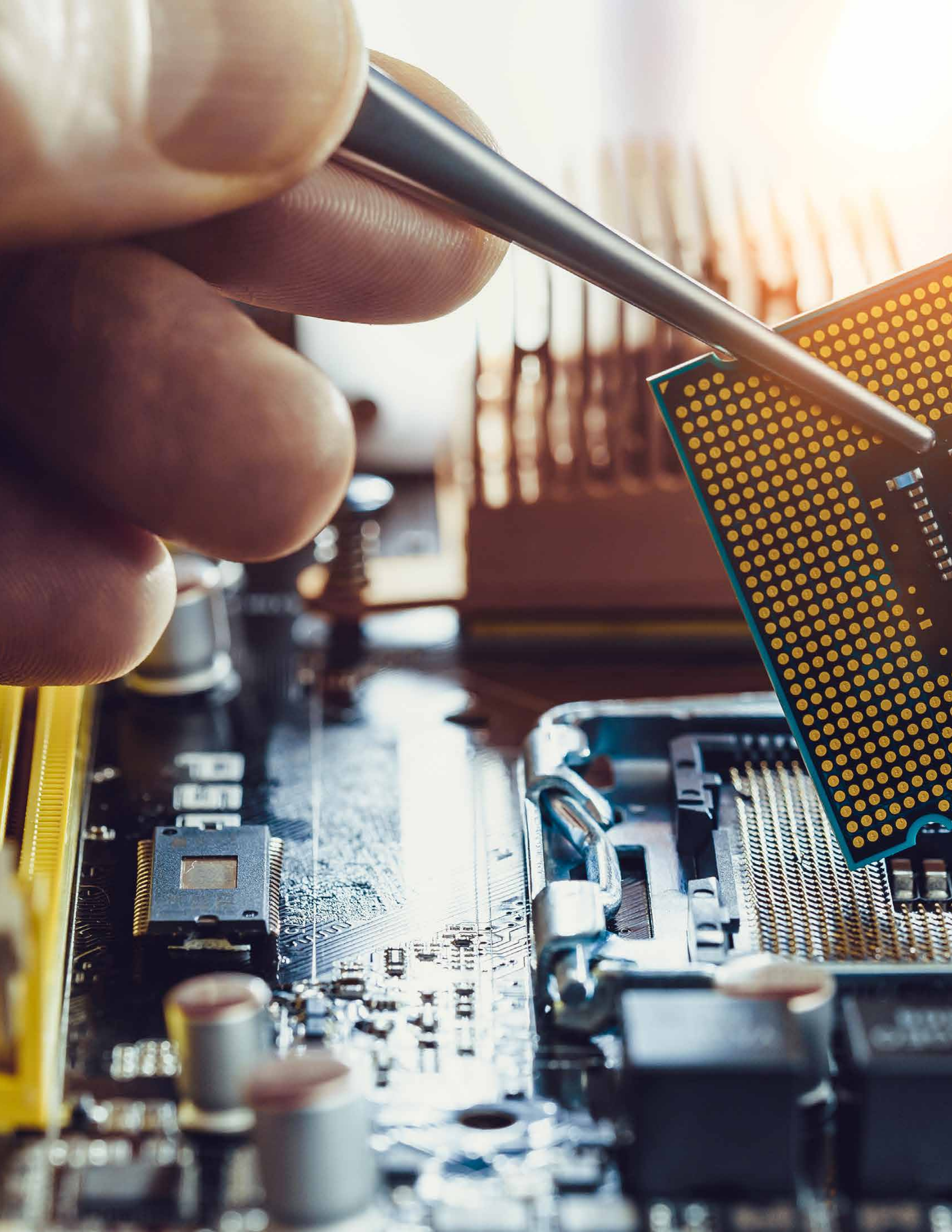
This time is no different

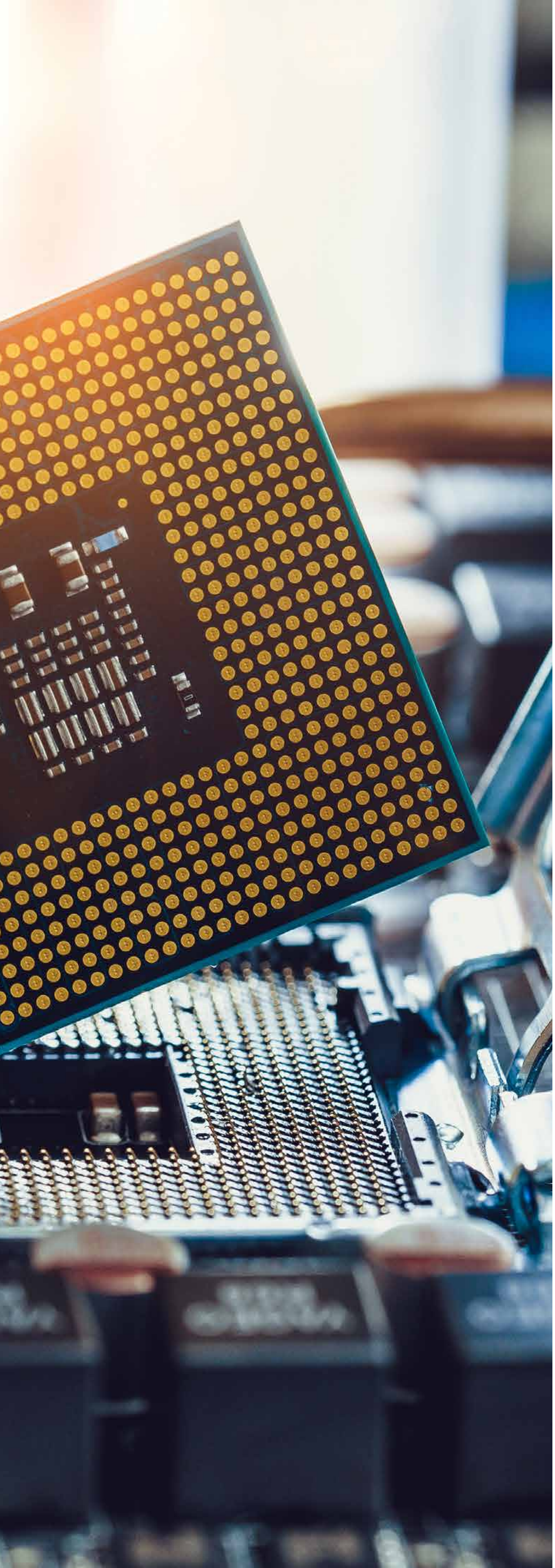
Hence, while we understand that there is no absolute guarantee that the current technological disruption will not permanently shrink jobs available for humans just because that has always been the case in the past, we very much support this point of view. We would argue that in every past period of technological disruption, jobs that were thought of as completely safe from the impact of automation ended up being impacted. In that sense, this wave of disruption is not different from ones in the past.

The weight of historical evidence, as well as common sense, very much suggests that the 'lump of labour' argument will remain a fallacy.

38 https://www.mskcc.org/about/innovative-collaborations/watson-oncology

39 http://www.bbc.com/culture/story/20180112-is-this-the-worlds-firstgood-robot-album





Technology can and does hold down wages

But while technology does not portend a jobless future, it can often be a force for wage disinflation. At first glance, it seems counterintuitive. After all, don't technological gains improve productivity? And shouldn't this in turn cause per capita wage growth?

Every major economy has seen historically low unemployment rates in the past decade: 4.1% in the US, 2.4% in Japan, 3.6% in Germany and 4.3% in the UK.[40]

Such levels of joblessness normally concern central bankers worried about a resulting explosion in wage inflation. Yet in every major economy, both wages and overall inflation have been extremely well contained, especially adjusted for the magnitude of job creation.

There are several possible explanations for this phenomenon. Workers might be more reluctant to move and have less confidence in their pricing power after the trauma of the 2008 financial crisis and its aftermath. Labour unions, especially in countries such as the US, have continued to lose power. But with every year that passes, these explanations seem less relevant. Presumably, at some point, the financial crisis should be firmly behind us. And labour unions have been losing influence and members for decades, with the Congressional Research Service showing that labour union share of the workforce peaked in 1954 and has been coming down ever since. Yet every year seems to bring an ever-lower jobless rate and puzzlingly low wage growth.

40 Bureau of Labor Statistics, Office for National Statistics, Statistisches Budesamt, Japan Ministry of Health, Labor and Welfare, Haver Analytics

Soft, not hard automation, has the biggest impact

The phenomenon of low unemployment/low wage inflation is not unique and has happened repeatedly in the past. For example, textile output rose dramatically in the early 19th century with the introduction of the power loom, and so did jobs in the sector, but wage growth failed to keep pace.

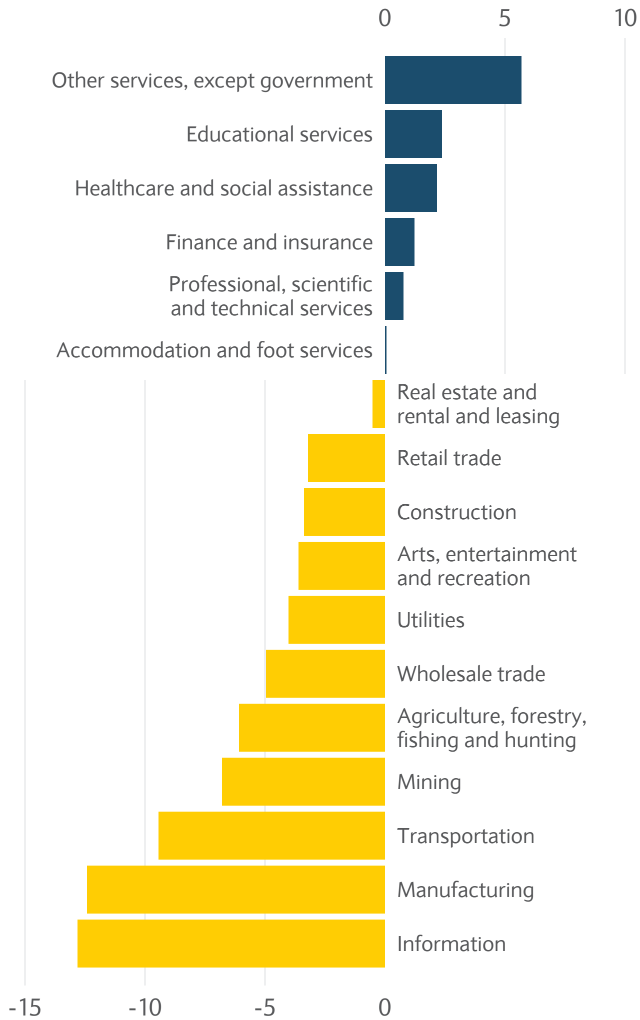
Closer to home, the IMF showed that technology is the biggest reason why the US labour share of income has been on a secular downward trajectory since the turn of the millennium, even as the recovery has seen robust job creation.[41] The IMF concluded that the routinisation of tasks within a variety of industries and occupations explained a little over half (44% to 57%, depending on the occupation) of the decline in labour's share of national income (Figure 13).

The reason that technology exerts this downward gravitational pull on wages, we believe, is because for the first several years or even decades, even the most path-breaking technologies end up automating specific tasks within a job, not the job itself. A recent McKinsey study argued that about 60% of all jobs could end up with about a third of their constituent tasks being taken over by technology.[42] But the study also forecast that only five percent of jobs would end up being fully automated. Soft automation, where certain parts of a job are automated away by technological change, has far more of an effect for the first few decades of technological disruption than hard automation, where technology fully substitutes for labour.

"For the first several years or even decades, even the most path-breaking technologies end up automating specific tasks within a job, not the job itself."

Figure 13

Labour share of US national income by industry: Median change across states (Change over 2001–14 in percentage points)



Source: https://www.imf.org/en/Publications/WP/Issues/2017/07/24/What-Explains-the-Decline-of-the-U-S-45086

41 Abdih, Y.A. & Danninger, S. (24 July 2017). *What Explains the Decline of the US Labor Share of Income? An Analysis of State and Industry Level Data.* IMF. Retrieved from https://www.imf.org/en/Publications/WP/Issues/2017/07/24/What-Explains-the-Decline-of-the-U-S-45086

42 https://www.mckinsey.com/global-themes/digital-disruption/harnessing-automation-for-a-future-that-works

The trucking example – lots of jobs, yet stunningly little wage growth

Soft automation is best explained through the example of one of the largest employers in the US – the trucking industry. The American Trucking Association (ATA) states that there are 3.5 million truck drivers in the country.[43]

The industry has seen very little hard automation. Tesla recently introduced a truck with self-driving technology and Uber is experimenting with a few driverless trucking routes. Meanwhile, the ATA has said that there is currently a shortage of truckers, and it will only grow over the next few years.[44] Clearly, technology has so far had a negligible impact in terms of cannibalising trucking jobs.

Yet, nominal wage growth for long-haul truckers has been shockingly poor over the years. The National Transportation Institute estimates that the median trucker wage in 1980 was a little over $38,000. By 2013, the median trucker wage was still close to $40,000. In real terms, wage growth in the trucking industry has been sharply negative. We believe soft automation is the main reason.[45]

Power steering in long-haul trucks was an important development for the trucking industry. Suddenly, physical strength was not a prerequisite to drive a 'big rig', expanding the potential pool of truckers. The introduction of rear-view cameras, cruise control, automatic braking technology and radar all made it easier to drive a long-haul truck. What was once a skilled job became less so with every new improvement, which in turn expanded the potential labour pool greatly. But it also explains why wage growth has been disappointing in the sector, even with lots of job creation.

Trucking is an example of an industry where steady improvements in technology have undercut wage growth for decades. In the last decade, this process has sped up in other sectors. Consider the experience of London black cabs since Uber entered the city in 2012. Becoming a black cab driver in London famously involves mastering 'The Knowledge', a highly detailed compendium of the city's roads, streets and buildings. The process takes two to four years, can cost tens of thousands of pounds, and involves memorising thousands upon thousands of street names and landmarks. Dropout rates are high, but passing the test has historically been considered a ticket to the British middle class. Uber's entry into London, coupled with improved mapping technology, changed all that.

Five years after Uber entered the London market in 2012, there were far more Uber drivers than black cabs, the Uber app had been downloaded 3.5 million times in London, and black cab drivers had staged a series of protests about how Uber was destroying their livelihood. Technology allowed 'The Knowledge' to be digitised into an app that anyone could use, reduced the skill set needed to be a cabbie in London and thus expanded the labour pool of potential cab drivers and drove down black cab drivers' wages.

43 http://www.trucking.org/News_and_Information_Reports_Industry_Data.aspx

44 http://www.trucking.org/article/New%20Report%20Says-National-Shortage-of-Truck-Drivers-to-Reach-50,000-This-Year

45 Though deregulation of the trucking industry definitely played a role in the first few years after 1980.

Who stole my productivity?

The 2017 OECD review of long-term productivity trends in major economies makes for grim reading. Labour productivity growth slowed sharply in OECD economies over the past several years, predating the 2008 financial crisis. Between 2005 and 2015, the OECD estimated that aggregate productivity in 30 major economies was just over 1%, compared with 2.5% in the previous decade – a marked decline in productivity and global growth.

Don't blame the financial crisis

The US has seen a similar trend. For example, the Bureau of Labor Statistics shows that non-farm private business labour productivity averaged just 1.3% between 2005 to 2015, a sharp drop from the 2.8% between 1995 to 2004.

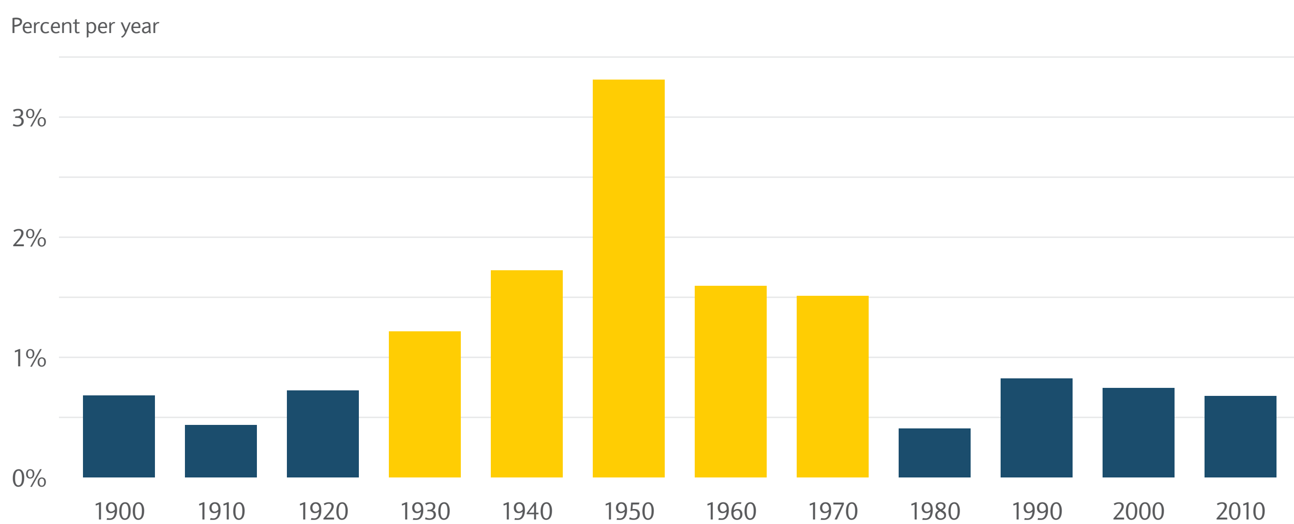
In the 2014 paper, "Productivity and Potential Output Before, During, and After the Great Recession", the authors estimated that by 2013, the US economy would have been almost $2 trillion dollars larger if productivity had stayed on the path of the previous decade. And that gap has only gone up over the last five years, as productivity has stayed anemic relative to 1995–2004.[46] Two conclusions can be drawn:

- Productivity in every major economy slowed sharply over the last decade-plus, in stark contrast to the decade prior, and
- This slowdown comfortably predated the Great Recession, starting around 2005 in most countries.

Consider productivity behaviour in the US (the epicenter of the 2008 crisis) in the past decade. John Fernald, an economist at the Federal Reserve Bank of San Francisco, writes that even though the housing and finance sectors were instrumental in causing the financial crisis, they could not be blamed for the productivity slowdown. For one, when the bubble burst, the productivity slowdown in finance-related sectors was less than that in non-finance parts of the economy. Second,

Figure 14

Annual growth rate of total factor productivity for ten years preceding years shown



Source: Gordon, R. (2015). *US Economic Growth is Over: The Short Run Meets the Long Run*. https://www.brookings.edu/wp-content/uploads/2016/07/tt20-united-states-economic-growth-gordon.pdf

46 https://www.frbsf.org/economic-research/files/wp2014-15.pdf

the slowdown was not concentrated in states where financial services are an outsized portion of the economy, such as New York. And third, US housing wealth peaked during 2005–2007, while the productivity slowdown itself started at the end of 2004.

So if the Great Recession is not to blame for lagging productivity, what is? If most of the path-breaking leaps in technology – the digitisation of economies, the collapse in data storage costs, the leaps in machine learning – largely occurred after 2005, why did productivity slow so sharply?

And why should one believe that machine learning and AI developments are truly a game-changer if they are not causing a jump in productivity and, thereby, growth? Is all the talk about how the AI revolution is changing industries and economies just that – talk?

Productivity spurts lag behind technological leaps…

The trends of the last decade are not only explainable, but also perfectly consistent with a period of rapid technological innovation.

Moreover, this pattern of technological leaps not showing up in productivity and growth data for many years is not new.

The great technological leaps of the past 200 years were arguably the steam engine and its applications, followed by the automobile and electrification of the economy. Most of this happened in the years just before and right after the turn of the 20th century. Yet, as Figure 14 shows, productivity languished in the 20 years between 1900 to 1920, even as all of these game-changing inventions were making it into the mainstream. By contrast, productivity growth averaged 1.5% or more in every decade from 1940 to 1980, including a dizzying 3.3% between 1950 to 1960, a period not associated with economy-changing technological advances.

In this context, the productivity experience of the last decade (even with the emergence of machine learning and other technological jumps) suddenly does not seem so outlandish. And it does not diminish the possibility that the technological breakthroughs of recent years could fundamentally reshape many areas of the economy.

…but adoption of new technology can have exponential effects on productivity

New technology takes time to hit critical mass. Economies of scale kick in on the production side, consumer behaviour starts to adapt, companies using the technology refine (and often change) their business models, and supplemental innovations greatly increase adoption.

In the case of electricity, while Edison is credited with the technological breakthrough of a viable light bulb, it was Samuel Insull who made the business feasible by consolidating small electricity providers to create economies of scale, refined the company's business model and generally drove widespread adoption.

It is very difficult to forecast when a new technological spurt will show up in the productivity statistics. After all, the most productive decade in US history was 1950–1960, a few decades after truly game-changing developments such as electrification and the automobile. But if a technology truly makes an impact – such as electrification and the automobile – adoption ultimately moves at an exponential pace. And the impact does ultimately show up in the productivity and growth numbers, although the lag may be longer than anyone thought possible.

Explaining the lags

But why are there such long lags between the introduction of a new technology and the effects showing up in productivity and growth data? The reason: an economy typically needs several years to decades to fully integrate a game-changing technology. Companies need to build up a critical mass of capital stock in the new technology, workforces need to be retrained, consumer behavior needs to adapt, business models need to be adjusted etc. All of this takes time. Only after that do the productivity gains flow. Consider past such examples: in 1882, the Edison Electric Illuminating Company of New York started lighting up parts of Manhattan. This was a truly revolutionary technology with arguably immediate effects on productivity, since it lengthened the working day and allowed people to use their time productively even when it was dark. But it wasn't until 1925 that half the homes in the US finally had electricity.

Automobile adoption has a similar history. Karl Benz, whose name would eventually headline one of the world's largest car companies, had an internal combustion engine car in Germany in 1885, as did Gottlieb Daimler. Shorty thereafter, Henry Ford started selling his own cars in the US. But by the turn of the century, only a few thousand cars had been sold in the US.[47]

The rise of the internet by the early 1990s was supposed to up-end all retailing. Pets.com was set to revolutionise sales of pet supplies. Etoys.com was supposed to do the same for toy sales. WebVan was going to do the same thing for groceries. All three went bust within a few years. By 2000, ecommerce sales were barely 0.5% of all retail sales by Census Bureau estimates.

Seventeen years later though, the hype is starting to feel justified, with the Census Bureau estimating that online sales made up 10% of all retail sales in Q3 2017, and grew at over 15% annualised while all retail sales grew in the low single digits. Second- and third-tier retail malls all across the US are in trouble as anchor tenants get squeezed by online sales. When Amazon bought Whole Foods, for example, the stocks of several leading grocery chains dropped sharply.

The retailers that are now online leaders needed time to understand the opportunity of the internet. They needed time to change consumer behaviour and to refine the logistics of efficient order fulfillment, delivery and the like.

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47 https://www.fhwa.dot.gov/ohim/summary95/mv200.pdf

Tackling the challenges ahead

Technology is fundamentally reshaping the nature of work, and this process is likely to accelerate in the coming decades. It is unlikely to create a jobless future and should eventually cause a jump in productivity, as has happened after past technological spurts. But technological progress is not an unambiguous positive and comes with its own challenges.

The Industrial Revolution polluted skies and rivers, led to terrible working conditions on assembly lines, and exploited child labour. It also led to massive concentration of power and wealth, giving rise to the original 'robber barons'. Over time, society found solutions. Child labour was outlawed in most economies, and primary education made compulsory. The US passed the Sherman Anti-trust Act in 1890 and forced the breakup of Standard Oil a few years later. Income tax collection became more progressive and governments spent more money on public services. The UK passed its Clean Air Act in the 1950s and other economies followed.

The challenges posed by technology echo the past in some respects, though not in others. One recurring challenge in the past few decades is that geographical areas that are heavily dependent on one industry are especially vulnerable to technological change in it. The social effects of such changes have been especially visible in some regions of the US. A hollowing out of the middle class, a rise in school dropout rates, a higher share of children raised in single parent homes, increased risk behaviour and, in recent decades, an opioid crisis: all of these can be traced back, at least in part, to technological changes (often coupled with globalisation), leaving certain geographies economically destitute.[48] The prescribed solutions tend to include government help in retraining and re-education, a strengthening of the social safety net, and attempts to diversify an area's industry footprint – take, for example, the number of US cities that aggressively bid to be chosen as Amazon's second headquarters recently.

Another challenge involves job and wage polarisation. It has been demonstrated that high skilled non-routine jobs, as well as non-routine manual employment, were less likely to be affected by technological shifts, but middle skill workers were likely to be negatively affected, including through depressed wage prospects.[49] Moreover, education may not be the panacea it once was; empirically, the 'education premium' has slowed in recent years.[50] Data scientists and on-call plumbers might both have a future, but not workers in jobs that can be routinised away. More targeted retraining, including vocational courses tailored to the digital age, is likely to be part of the solution.

There are many other areas that will challenge policy makers of the future. Do large tech platforms have too much power, encouraging monopolistic behaviour and stifling the rise of new startups? Do data privacy laws need to be strengthened given the explosion in social media? There are already signs that regulators, especially in Europe, are starting to respond to these challenges, including through anti-trust related fines, new laws that prevent tech firms from using low tax havens, regulation that makes large platforms more responsible for the content they allow to be posted, and so on.

And more radical solutions might well be needed as this new wave of technology leads to wealth creation that is ever more concentrated. For example, a national wealth fund (akin to Norway's sovereign oil fund) that allows the general population to share in the economic benefits of technology might someday make sense for some countries. Historically, society has always found a way to absorb the positive effects of technological change while responding to the challenges such change poses; that is likely to be true in the future as well.

48 Autor, Dorn and Hanson (2017), Krueger (2016), Case and Deaton (2015 and 2017).

49 Autor, David H. and Dorn, David, *The Growth of Low Skill Service Jobs and the Polarization of the U.S. Labor Market*. IZA Discussion Paper No. 7068. Available at SSRN: https://ssrn.com/abstract=2192764

50 Valletta (2017)

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