>TECHNOLOGY'S IMPACT ON GROWTH AND EMPLOYMENT

Adam Saunders

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Image: Men select their food served by robot waiter, which moves on a rail system placed between tables, at the first robotic restaurant 'RoboChef'.

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>TECHNOLOGY'S IMPACT ON GROWTH AND EMPLOYMENT

Technology has always fueled economic growth, improved standards of living, and opened up avenues to new and better kinds of work. Recent advances in artificial intelligence and machine learning, which brought us Watson and self-driving cars, mark the beginning of a seismic shift in the world as we know it. To navigate the unstable labor market and seize the plentiful opportunities offered by new technologies, we must find a way to more quickly adapt. By continually updating our skills and seeking alternative work arrangements, we can "race with the machines." Whether we like it or not, change is coming, and the worst move of all would be to ignore it.

Introduction

Recent advances in artificial intelligence and machine learning, which brought us *Watson* and self-driving cars, mark the beginning of a seismic shift in the world as we know it. But major innovations (defined as widely-used technologies that improve over time and have spillover effects that provoke further advancements) have been around since the beginning of recorded history. From the first metal tools, to the wheel and the printing press, these innovations (dubbed general purpose technologies, or GPTs[1]) have changed the course of history. GPTs "interrupt and accelerate the normal march of economic progress".[2] In other words, they make humans more productive and increase standards of living. They also help open avenues to new kinds of work.

Erik Brynjolfsson and Andrew McAfee succinctly divide historical progress into two machine "ages".[3] The first machine age dates back to the invention of the steam engine, by James Watt in 1775. This brought about an explosion of innovation, and resulted in an increase of living standards to such an extent, that the average American today has a quality of life that was unimaginable to even the wealthiest nobles of that era. The "second machine age" began in the 1990s, and is characterized by three factors: (1) exponential increases in computing power, known as Moore's Law; (2) the agility and power of digital technologies (including their ability to replicate ideas and products at zero or low cost); and (3) our creative ability to build off of ideas like building blocks, in order to create innovations (called recombinant growth).[4]

Even more fascinating, is that "Moore's Law" —which has driven so many changes in technological progress— has held up amazingly well over the years. In 1965, Gordon Moore, who was then the director of research and development (R&D) at Fairchild Semiconductor, predicted that the overall processing power for

computers (or the number of transistors in an integrated circuit) would double every year. This prediction became known as Moore's Law. (Moore then revised the prediction in 1975 to every two years. He also later became the CEO of Intel.) While Moore originally made his prediction for a period of ten years, exponential increases in computing have continued even up to present day. What's more, William Nordhaus has actually traced back Moore's Law back to the earliest adding machines from circa 1850.[5] The exponential growth of computing power makes it seem as though new technologies come out of nowhere; in reality, however, they've been around (albeit also very expensive and rare) for quite a while. In the past, only the rich could benefit from the latest innovations.

For example, Brynjolfsson and McAfee illustrate this astonishing speed of progress by comparing the technologies available in 1996 and 2006: In 1996, the ASCI Red was the world's fastest supercomputer. It cost $55 million to develop, and occupied 80% of the space in a tennis court at Sandia National Laboratories in New Mexico. It took as much electricity as was needed to run 800 homes. In 1997, it hit 1.8 teraflops. In 2006, ten years after the ASCI Red was introduced, the Sony Playstation 3 hit 1.8 teraflops. It cost only $500, took up less than one-tenth of a square meter, and drew as much power as one lightbulb.[6] McAfee and Brynjolfsson provide another example, displaying the rapid adoption of smartphones: "By 2015, only eight years after the iPhone was introduced, more than 40% of the adults in 21 emerging and developing countries surveyed by the Pew Research Center reported owning a smartphone. In 2016, approximately 1.5 billion more were sold."[7]

"GENERALLY SPEAKING, TECHNOLOGY HAS INCREASED THE SIZE OF 'ECONOMIC SURPLUS PIE' AND REDISTRIBUTED MUCH OF IT TO CONSUMERS."

As a thought experiment, let us consider the computing power we will have in our hands in twenty years if Moore's Law continues to hold (as we have no reason to think otherwise, given its faultless track record). Suppose the cost of computing falls in half every 18 months. Then, a thousand dollars of computing power today (approximately the cost of an unlocked iPhone 8 Plus with 256GB memory in 2017) would cost less than ten cents by 2037.[8] While that may seem astonishing, ask yourself how much would you pay for a cell phone made twenty years ago? If we assume that consumers, twenty years from now, would be willing to pay a thousand dollars for whatever smartphones are on the market at that time, what would be the cost of such technologies, if we could get them today? A little more than ten millio n dollars.[9] Imagine if you could have a smartphone with ten million dollars of computing power ——that is a rough approximation of what will be in everyone's hands in about two decades. In other words, as Hal Varian, chief economist at Google, says, "A simple way to forecast the future is to look at what rich people have today."[10]

Technology and Labor

The average American today has better medical care, better access to information and education, and better ways to communicate and travel than the richest people in the world in the not-very-distant past. We have experienced a dramatic increase in living standards, whose "single most important determinant [...] across countries and over time" is labor productivity.[11] Productivity—equal to output divided by inputs (such as capital, labor, energy, materials, and services)—increases when we deploy technology.[12] The Council of Economic Advisers gives us an example of incredible improvements in agricultural productivity over the past two centuries: "In 1830, it took 250-300 hours for a farmer to produce 100 bushels of wheat. In 1890, with horse-drawn machines, it took only 40-50 hours to produce the same amount. By 1975, with large tractors and combines, a farmer could produce 100 bushels of wheat in only 3-4 hours."[13] By producing more output, given the same value of inputs, agricultural machines decreased production costs. As a result, food became more affordable and people became less likely to die of starvation. In addition, the increased productivity from the automation of agricultural work led farm workers to migrate to cities, where they then helped the industrial economy develop and grow. New goods and services were created, and consumption increased. Productivity rose even more as automation drove down costs, thereby making transportation, healthcare, education, and government more affordable.[14]

Generally speaking, technology has increased the size of 'economic surplus pie' and redistributed much of it to consumers. Consider one example: When Amazon offers free same-day or next-day delivery, that delivery is not actually free — it costs Amazon notable resources to achieve this. The gains from Amazon's investments in automation and improvements in its supply chain are reflected as a combination of lower prices, greater variety, and faster delivery, as the firm competes to win over consumers. From this perspective, we can understand how it's understandable that William Nordhaus had estimated a whopping 96% of gains from technology go to consumers, not producers.[15]

As wonderful as the gains of technology have been, they are also occurring against a backdrop of rising inequality, a shrinking middle class, and difficulties in finding employment. From the 1940s to the 1970s, incomes at all levels grew at approximately the same rate in the United States. However, since then, the wealthiest Americans have seen significant gains in their income and share of wealth, whereas the rest of the income distribution has seen much more modest gains. Consequently, as America's middle class has shrunk, an unfortunate opioid epidemic has ravaged the country in areas with high unemployment.[16]

Thus, it is important to remind ourselves that automation does not have a universal effect on employment; a machine can be either a *substitute* or a *complement* to human labor.

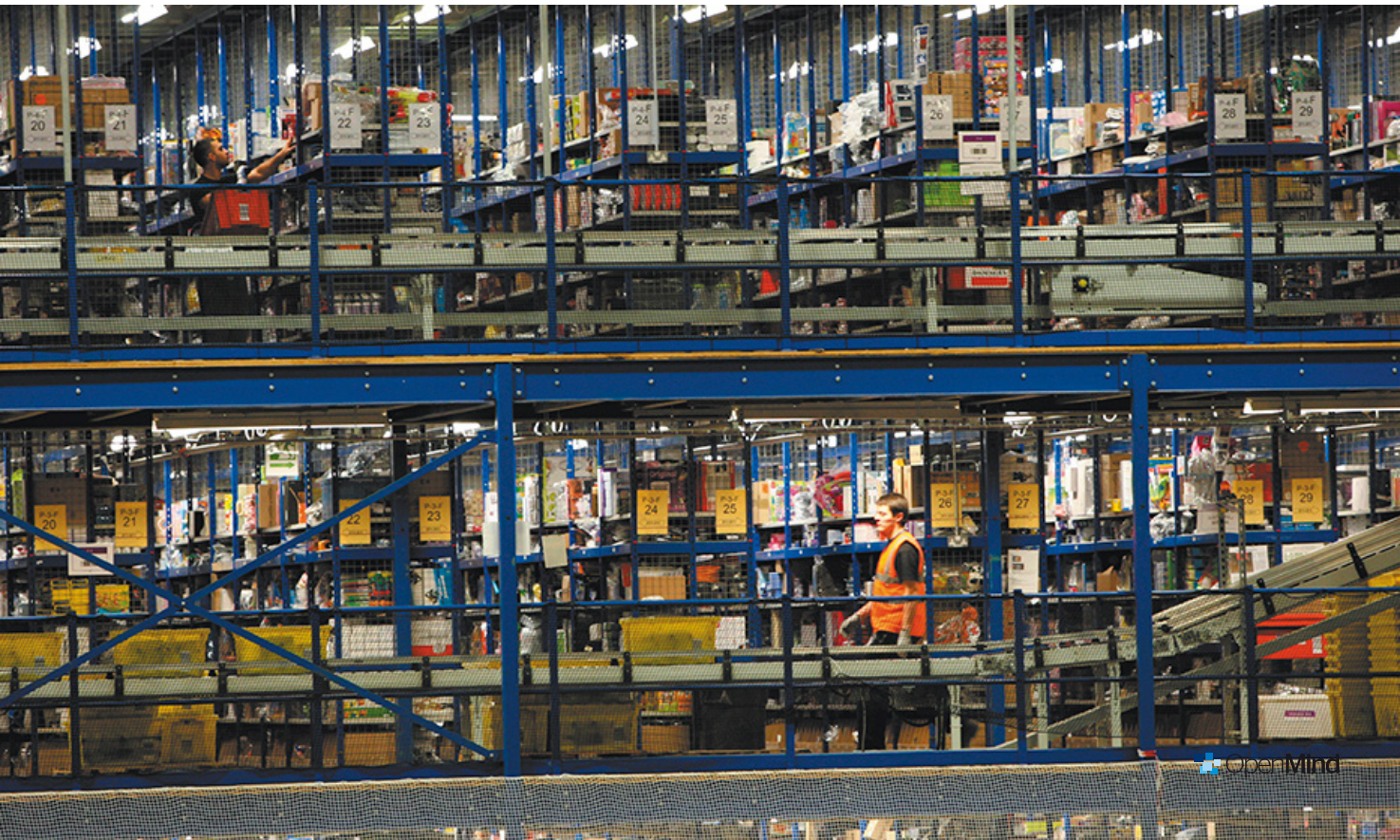
A machine can *substitute* for human labor when it has the ability to produce more than the worker for the same cost (such as his or her wages), or as much as the

worker for a fraction of the price. This is most likely to occur when a worker's tasks are routine and codifiable—that is, when the instructions for the tasks can be translated into code for a computer to carry out. In addition, automation is more able to replace workers in simplified, controlled environments. While computers can perform the most complex calculations in milliseconds, it is much more difficult to get a machine to write novels or care for children as effectively as humans do.

Machines *complement* labor when they allow workers to be more productive, but cannot—at least cannot *fully*—replace the worker. In other words, automation that complements human labor makes it easier for people to do their jobs and concentrate on what humans excel in, such as idea generation, problem solving, pattern recognition, and complex communication—all of which constitute computers' weaknesses.[17] For example: calculators, spreadsheets, and bookkeeping software all made accountants' jobs much simpler. For the most part, however, humans are still the ones making insights and providing strategic advice to the businesses they work at.

Various kinds of automation already complement human labor (e.i., big data-collecting robots that allow people to do more valuable work —and telescopes, which have helped humans make discoveries that would have otherwise been impossible). Tom Davenport and Julia Kirby refer to this "mutually-empowering" relationship between humans and machines as *augmentation*, which they distinguish from the process of automation, which simply substitutes for labor.[18] Additionally, as David Autor points out, because machines increase labor productivity and lower production costs, they allow us to more easily create goods and services.

Workers sorting Christmas presents at the Amazon warehouse in Milton Keynes, Bucks.



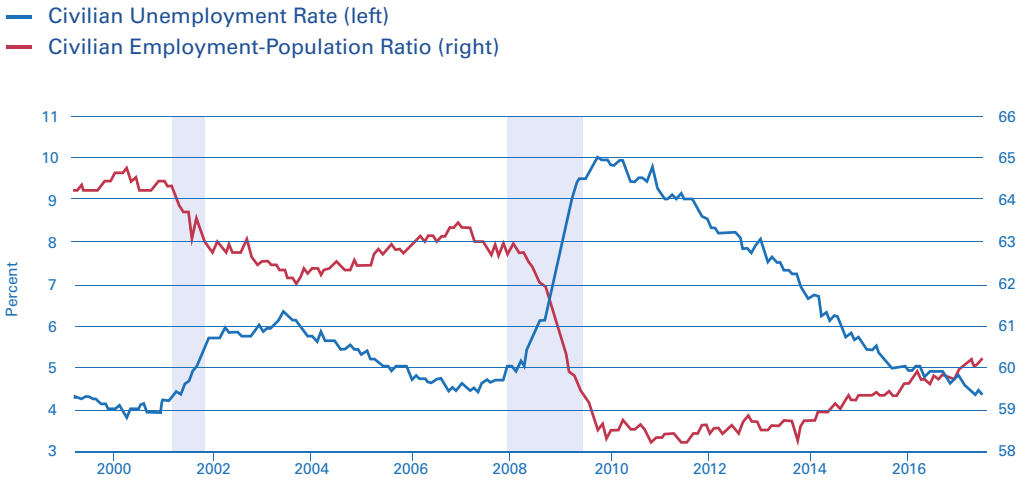
The Current Labor Market

Throughout history, machines have helped workers to produce more output. In spite of concerns that automation would get rid of jobs or cause mass unemployment, technology has continually led to the creation of new jobs. In fact, history has proven that as labor productivity grew, so too did job growth. (This has not been the case recently however, a point we will return to).[19]

The employment-to-population ratio (i.e., the share of the total US working-age population, aged 16 and above, that is employed) increased during the 20th century, even as more women entered the labor force.[20] The development of machines increased productivity and decreased production costs, allowing the creation of mass production. The subsequent surge in economic growth during this period led to the evolution of consumerism, and thus, resulted in increased job creation. However, as Autor has noted, "there is no apparent long-run increase" in the ratio which has fluctuated over the years—and falling especially during recessions.[21]

Since 2010, the national unemployment rate has continued to fall. In more recent years, the rates have mirrored the levels experienced prior to the Great Recession (see Figure 1). Nevertheless, these statistics are misleading, as the employment-to-population ratio hasn't remained stagnant. Before the recession in 2007, about 63% of working-age people in the United States were employed, and the unemployment rate was just under 5%. As of September 2017, the unemployment rate has dropped down to 4.2%, while the employment-to-population ratio has reached a little above 60%.[22]

Figure 1: US Unemployment Rate & Employment-to-Population Ratio



Source: Bureau of Labor Statistics from: Federal Reserve Bank of St. Louis
Note: Shaded areas indicate US recessions

One phenomenon masked by the unemployment rate is the trend of people leaving the workforce. People categorized as part of the workforce are those who are either employed or "unemployed" (meaning they don't have jobs, are available for work, and have actively looked for jobs in the past four weeks). For example, the most recent statistics indicate there are still roughly 6.8 million people unemployed in the United States.[23] However, there are about 1.6 million others not in the workforce—that is, they have no job and are not currently looking for work—but are considered "marginally attached", since they *want* a job, and *are* available for work, and have looked for a job in the last 12 months.[24] Almost half a million of these workers are considered "discouraged", because they have given up the search since "they believe no jobs are available for them."[25]

Take, for example, a coal worker with a high school education in West Virginia who used to earn an annual salary of $80,000, but was recently laid off because more sophisticated technologies were deployed in mines. It is unlikely that such a job will make a comeback —at least in West Virginia. Will this worker want to work for less than one-third his previous wage as a cashier? Suppose, instead, this miner stops looking for work because he is tired of finding nothing available and becomes increasingly unmotivated. This discouraged worker doesn't get factored into the unemployment rate, since, technically speaking, he is no longer a part of the labor force —despite how much he would actually want to work, if only he could have his old job back.

"THE AIRLINE INDUSTRY IS AN INTERESTING EXAMPLE OF AUTOMATION. THE MAJORITY OF PEOPLE BENEFIT FROM ITS ADVANCEMENTS, BUT A GROWING NUMBER OF EMPLOYEES SIMULTANEOUSLY SUFFER PAINFUL JOB LOSSES."

Now consider the future of a much larger group of workers: once self-driving cars are deployed more widely, many of the 3.5 million truck drivers in the United States could lose their jobs.[26] Some long-haul truck drivers make as much as $150,000 per year.[27] As is the concern with coal miners, will these drivers find jobs with similar salaries if they do not have more than a high-school education?

People may wonder, "Where have all the jobs gone and why have they disappeared?" Some blame immigrants, trade agreements, or advancing technology —while some blame a combination of all three. The reality, however, is more complicated. At least with regard to technology, automation has both created and taken away jobs. There are both winners and losers. Workers in Silicon Valley, as well as those with backgrounds in statistics and economics, are thriving in the current economy. As Google's Chief Economist, Hal Varian, remarked, "the sexy job in the next ten years will be statisticians."[28]

The airline industry is an interesting example of automation. The majority of people benefit from its advancements, but a growing number of employees simultaneously suffer painful job losses. Automation has affected almost every job in the industry, from the flight booking process, all the way to border control. Most of us book flights online, use automated check-in counters and passport scanners, fly to our destination primarily by computers on airplanes, and pass through border control with self-serve kiosks. While there are still people who assist us, many jobs have also been removed from each stage of the process. On the other hand, the increased automation has, for the most part, made flights safer and cheaper.[29] Moreover, the Internet has empowered travelers by allowing them to much more easily compare ticket prices charged by various airlines for various routes. This transparency has led to increased competition that have helped airline ticket prices drop by 50% in 30 years[30] ——serving as another illustration supporting Nordhaus's study, in which consumers receive 96% of the gains from technological innovation.[31]

On July 31, 2009 (right after the Great Recession) job openings in the United States had hit a low of 2.2 million —while civilian unemployment was as high as

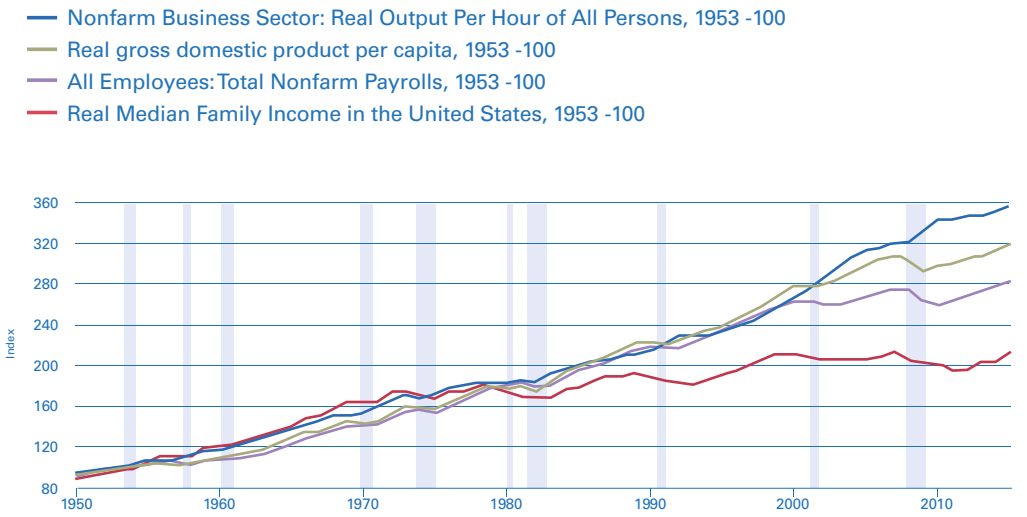
Engineer inspecting a tunnel boring machine which has completed the excavation of a deep access power cable tunnel in London.

14.6 million.[32,33] Yet, job openings have been increasing, particularly in professional and business services, healthcare and social assistance, and construction.[34] In fact, in August 2017, they surged to an all-time high of 6.1 million.[35] As far as we can tell, there are more jobs available today, than there have been in the last seventeen years —which is when the BLS first began to measure them.

On the aggregate level, the situation doesn't look so bad: If there are 6.1 million jobs available, then 6.1 million out of the 8.4 million people looking for work (unemployed and marginally attached to the workforce) no longer have to be out of work. In reality, however, it's much more difficult than that. People are not being matched to jobs for various reasons—because they are not qualified enough (or overqualified), or are in fields (and physical locations) where jobs are disappearing. The macro-picture misses the micro-stories.

So, even as labor productivity has increased—an effect usually accompanied by job growth—private employment has essentially remained stagnate since 2000.[36] (See Figure 2.) (Real median family income and real GDP per capita also "decoupled" from labor productivity in the early 1980s and the 2000s, respectively.) Brynjolfsson and McAfee call this effect the 'Great Decoupling', and attribute a portion of these effects to the emergence of digital technologies.[37] They don't see these gaps closing anytime soon.

Figure 2: The Great Decoupling



Sources: Bureau of Economic Analysis, Bureau of Labor Statistics, Census Bureau
From: Federal Reserve Bank of St. Louis; Erik Brynjolfsson and Andrew McAfee
Note: Shaded areas indicate US recessions, data from 1953 until 2015

Alternative Work Arrangements

Lawrence Katz and Alan Krueger discovered that on top of the slowdown in employment, 94% of the net job growth from 2005 to 2015 was simply in temporary or unsteady work—as opposed to the previous decade, during which there was almost no growth in such "alternative work".[38] As increasingly more tasks are being handled by machines—which are not only simply more efficient than people, but also, unlike humans, don't demand high wages, vacations, health insurance, and pension plans—companies now require fewer workers or fewer hours from their workers (or both). But while there might not be as many (full-time) jobs left, there is still a lot of work. As Diane Mulcahy explains, "Work is being disaggregated from jobs and reorganized into a variety of alternative arrangements, such as consulting projects, freelance assignments, and contract opportunities."[39]

Millions of people have been affected by these rearrangements. As of September 2017, there were 5.1 million "involuntary part-time workers" who weren't able to find full-time jobs or whose work hours had been reduced by their employers.[40] However, according to the McKinsey Global Institute, 20% to 30% of the American working-age population (of approximately 206 million)[41] perform some type of independent work, which amounts to approximately 40 to 60 million people[42]——and this share, Mulcahy notes, is growing.[43]

Because jobs are no longer as stable as they have been, people have been turning to the "gig economy" to seek alternate forms of work. Thanks to two-sided platforms such as Uber, Lyft, Airbnb, Etsy, Samasource, Postmates, and TaskRabbit, people can now work whenever they want, as often as they'd like, more easily than ever. This benefits people young and old who do low-skill to high-skill work. Former taxi drivers can now dictate their own schedules with Uber and Lyft. Stay-at-home parents and people with disabilities are able to more easily find work and develop their skills with Samasource. Young artists can now sell their self-made products directly to their customers on Etsy. Elderly empty-nesters now have the ability to rent out their rooms on Airbnb to help give a boost to their own retirement funds. Freelance designers and coders also have the opportunity to contract out their work and take time off for their families and for vacations whenever they wish.

Clearly, the advantages of the gig economy go beyond providing cost-savings to firms and offering some sort of employment to workers. The gig economy offers "choice, autonomy, flexibility, and control", that which full-time jobs don't.[44] These benefits influence work satisfaction. They're why 74% of surveyed freelancers wish to remain independent workers and "have no intention of returning to a full-time job".[45] Indeed, says Mulcahy, "independent workers are more satisfied with nearly every aspect of their working lives than employees," and for these reasons, she advises her MBA students to seek "plentiful work, not increasingly scarce jobs" and to prepare to be "independent workers, not full-time employees."[46]

Job Polarization

In addition to affecting the quantity of jobs, technology can also have a great impact on job quality.[47] Some have concerns that automation steals jobs, while others insist that it actually improves them. In reality, both of these are true. Machines have affected jobs all across the skill spectrum—both increasing and decreasing the demand for jobs of different skill levels.[48]

Low-Skill Jobs

On the low side of the skill spectrum, the demand for jobs (i.e.: milkmen, switchboard operators, mail-sorters, dishwashers, ice-cutters, weavers, and assembly line workers) has fallen drastically —or even disappeared— because of technologies such as refrigerators, cell phones, and industrial machines. Although the invention of these technologies has driven out jobs, it's also allowed us to make certain forms of work more bearable. For example, by investing in industrial dishwashing machines, restaurants don't require as many human dishwashers. Consequently, the demand for dishwashing jobs would decrease, though some would still remain. These remaining jobs would then be simplified. Instead of doing the actual washing by hand, human dishwashers would only have to load and unload dishes.

"IT IS WE WHO DECIDE WHAT BECOMES OF TECHNOLOGY."

While it's easy to imagine other low-skill jobs dying out due to automation—as robots now have the ability to vacuum rooms, patrol buildings, and flip burgers (to name but a few tasks) —machines still aren't replacing low-skilled jobs in cleaning, security, and food service.[49,50] This is because although certain tasks may be automated, robots aren't able to take over entire jobs. For example, while dishwashing machines do an excellent job washing dishes, humans are not completely replaced in the process, as machines don't load or unload themselves. Humans still outperform machines, especially in jobs that involve manual skills and varying environments.[51] Therefore, there still is (and will be) a demand for low-skill jobs. In fact, as we'll see later, demand is actually increasing.

Middle-Skill Jobs

The middle part of the spectrum is a little more complicated. Middle-skill jobs (which include blue-collar production and operative positions, as well as white-collar clerical sales positions) are more likely to be codifiable. As a result, they've been disappearing, even though low-skill jobs haven't.

Some forms of automation force people to perform mind-numbing tasks. Think of how most artisans and craftspeople were replaced by assembly

line workers. In this process of "deskilling", middle-skill jobs get replaced by low-skill jobs. Meanwhile, some jobs simply die out, forcing workers to resort to lower-skill jobs. For example, most manufacturing job losses have been due to automation (rather than international trade, as politicians tend to suggest).[51] Workers previously in employed in the manufacturing sector have since had to turn to lower-skill and lower-paying in service sector to get by.[53] This increases job growth in low-skill work. According to the Organisation for Economic Co-operation and Development (OECD), about one-third of medium-skill jobs that have disappeared worldwide have been replaced by low-skill jobs.[54]

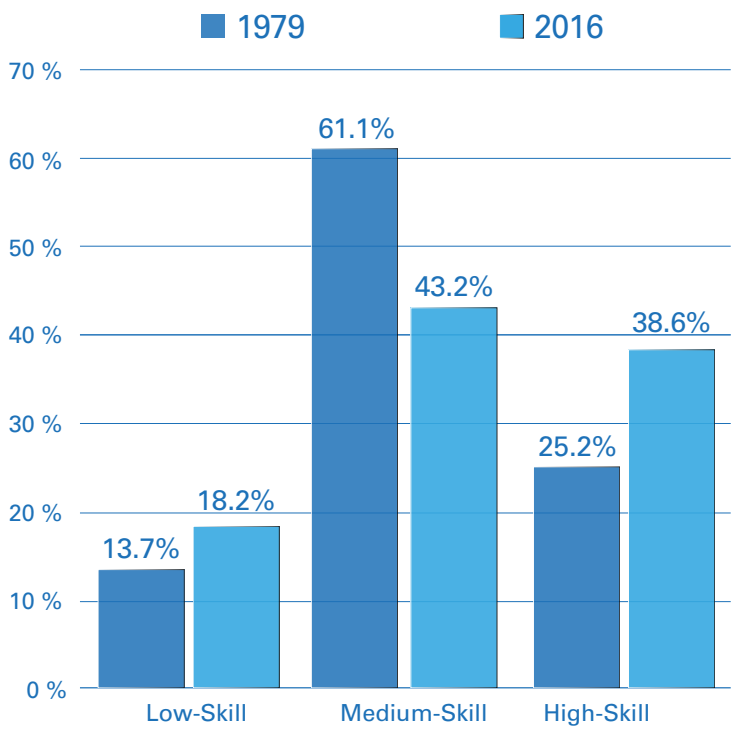
However, much like in low-skill jobs, other forms of automation can take out the danger and drudgery out of certain tasks, thereby allowing us to do safer and more meaningful work. For instance, although removing humans from coal mines might rob them of their incomes and jobs, fewer people now have to suffer from black lung disease or be threatened by deadly mine collapses. And while many bank employees may have been replaced as more customers use ATMs to conduct routine transactions, those employees who do remain can now, instead of counting cash, do potentially more important work, such as recommending financial services to clients. The OECD estimates that two-thirds of lost middle-skill jobs have been replaced by jobs that require higher-skill work, such as analysts and managers.[55]

High-Skill Jobs

Although technology has been widely known to displace lower-skill and blue-collar workers, high-skill occupations have, for the most part, been protected because jobs that require more training and more complex cognitive skills (such as analysis, problem-solving, and decision-making) are much less codifiable. As David Autor and others have noted, this makes white-collar professionals and knowledge workers such as doctors, programmers, engineers, marketing executives, and sales managers difficult to replace.[56] Therefore, even though recent developments in automation have targeted high-skill work, there is still growth on this side of the spectrum.[57] After all, to get the most out of their technological investments, firms have to hire workers who are more highly skilled and educated.[58]

Thus, we have ended up with a polarized workforce—an effect that's been occurring around the world.[59] As Autor has observed, job growth has increasingly become concentrated on the two opposite sides of the skill spectrum, while medium-skill jobs are shrinking.[60] Indeed, the share of US workers in low-skill and high-skill jobs both increased from 1979 to 2016.[61] (See Figure 3.) On the other hand, although just over 61% of US workers were employed in middle-skill jobs in 1979, this share fell to 43% in 2016.[62]

Figure 3: Share of US Workers in Low-, Medium-, and High-Skill Occupations



Adapted from Autor (2016).

As a result, those who aren't able to find employment could be facing two types of options—neither of which are good.[63] On one hand, there is a set of available jobs that aren't as rewarding or as satisfying as they were before, since they require fewer skills or offer lower wages. On the other hand, there is another set of jobs that could be more desirable, but these jobs are unattainable because they require a higher level of skill or education than the worker has achieved.

Race with the Machines

It's important to consider how technology has changed the labor market and the economy for the better for some, but for the worse for others. We should focus on finding solutions to the issues that have arisen (by ensuring job security, and supplying healthcare and retirement plans) while taking advantage of new opportunities (through new technologies, data and analytics, platforms, etc.) and remaining flexible as the times change.

Whether or not we like it, technology, and the increased competition from globalization of the workforce has changed labor markets. The days of steady, long-term, full-time jobs —especially with one single firm for one's career— are coming to an end sooner than we think. This is certainly difficult to accept for those who had been prospering in fields now rampant with automation. Regulation, trade barriers, or otherwise fighting and racing *against* machines will not be fruitful in the long term. Instead, as Brynjolfsson and McAfee like to say, we should continuously be investing in new skills to race *with* the machines.[64]

So how do we race with the machines? Davenport and Kirby, as well as Autor recommend that people focus on becoming tech-literate and on improving their manual and abstract skills.[65] Learning how to code in various computer languages and knowing how to collect and analyze data, for example, would be immensely helpful in the race with machines. Manual skills such as dexterity and flexibility will also still be valuable in the near future, and further developing innate human qualities (i.e., abstract skills that machines aren't good at—such as creativity, persuasion, empathy, pattern recognition, and complex communication) would certainly be beneficial.[66]

Davenport and Kirby identify five different ways for both people and companies to use such skills to succeed in the second machine age:[67]

Stepping up: Let machines do your dirty work, so to speak, thereby allowing you to focus your time and energy on making big-picture insights (e.g., managing investment portfolios).

Stepping aside: Use abstract skills, such as creativity or empathy, to do things that machines aren't good at or to explain decisions that computers made (e.g., communicating negative news).

Workers in an office building at night.

Stepping narrowly: Do things that would be too costly to be automated, such as specializing in a very particular area of a field (e.g., specializing in the legal issues pertaining to malfunctioning garage doors, or in connecting buyers and sellers of Dunkin' Donuts franchises).

Stepping in: Use tech skills to improve machines' decision-making abilities and to make sure that they function well (e.g., providing feedback to programmers by identifying bugs and suggesting modifications to be made).

Stepping forward: Use tech skills and entrepreneurial thinking to create advanced cognitive technologies (e.g., becoming a machine learning engineer).

The better that individuals and companies become at finding such complementary and "mutually empowering"[68] relationships that augment human labor with machines (or vice versa), the more likely it is that employment growth and job quality will improve. With more fitting skills, there would more people employed in more satisfying and meaningful jobs.

However, there will still be those who are left behind and who aren't able to find jobs in the increasingly unstable labor market. There's been much debate on whether a safety net in the form of a universal basic income should be provided to address the Great Decoupling, particularly the stagnant wages Americans have experienced for three decades.[69] Nevertheless, a guaranteed income won't fix all the issues we've been dealing with. Employment is important for one's well-being, providing many with a sense of purpose. As Voltaire once said, "Work saves us from three great evils: boredom, vice and need."

The fear that machines are taking over our jobs isn't a new one, and Autor compares the situation today to when many jobs in the agriculture sector were becoming automated a hundred years ago.[70] In 1900, farming used to make up 41% of the American workforce. A century later, the share decreased to just 2%.[71] If Americans had been told a century ago that due to new technologies and innovation, farmers as a share of the workforce would fall by 95%, most would probably consider it to be frightening news. What are people going to do? How could they have possibly imagined that people would become social media managers, app developers, cloud computing specialists, information security analysts, drone operators, solar and wind energy technicians, genetic counselors, vloggers, yoga instructors, and sustainability managers? Likewise, how can we expect to understand exactly what can be done in a world that doesn't yet exist with technologies that haven't even been invented?

As agriculture became automated, the United States responded to these changes by investing in its youth —they put children in school to prepare them for industry jobs. Similar actions must be taken today. As Mulcahy argues, the education system, now outdated, needs an overhaul. Instead of teaching children to prepare for jobs of the past, we should be preparing them for work in the gig economy of the future. So, schools and universities should prepare youths to be

agile and adaptable, and have a more significant focus on the skills Davenport and Kirby, as well as Autor, have recommended. Additionally, businesses and government policies should help retrain adults who have been left behind. Along with education, Brynjolfsson and McAfee recommend four other areas of focus to help create an economic environment that would "make the best use of the new digital technologies": infrastructure, entrepreneurship, immigration, and basic research.[72]

As the futurist Ray Kurzweil reminds us, we always underestimate the pace of technological change, because the technologies that will be invented in twenty years will not be invented with today's technology. It will be invented with the technologies available in twenty years, which of course, haven't been dreamed of yet. We can begin to imagine such a world, with smartphones in everyone's hands, that today, would cost us ten million dollars apiece. As David Autor suggests, (1) it's very difficult to predict the future and (2) it's arrogant to bet against human ingenuity.[73]

As many have pointed out, technology is just a tool.[74] It will not necessarily lead us to a utopian or dystopian world because we, as human beings, have a say in the matter. It is we who decide what becomes of technology. To paraphrase electrical engineer and physicist Dennis Gabor, we cannot predict the future, but we can invent it.[75]

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Notes

1 See Lipsey et al. (2005).

2 See Brynjolfsson and McAfee (2014, p. 76).

3 See Brynjolfsson and McAfee (2014).

4 See Brynjolfsson and McAfee (2014).

5 See Nordhaus (2007).

6 See Brynjolfsson and McAfee (2014, pp. 49-50).

7 See McAfee and Brynjolfsson (2017, pp. 17-18).

8 1,000*0.5^(20/1.5) = 0.10.

9 10,321,273.24*0.5^(20/1.5)=1,000.

10 See Varian (2011).

11 See Council of Economic Advisers (2016, p. 58).

12 The only ways to increase output are by increasing inputs such as population (i.e., by increasing the number of hours worked given the same level of productivity) or through productivity growth (i.e., by increasing output per hour, or the amount of output given the same level of inputs) (Brynjolfsson and Saunders, 2010).

13 See Council of Economic Advisers (2007, pp. 47-48).

14 See Pearlstein (2016).

15 See Nordhaus (2005).

16 See Case and Deaton (2017) and Hollingsworth et al. (2017).

17 See Davenport and Kirby (2016) and Autor (2015).

18 See Davenport and Kirby (2016).

19 See Brynjolfsson and McAfee (2014).

20 See Autor (2015).

21 See Autor (2015, p. 4).

22 See BLS Series LNS12300000, Employment-population ratio, 16 years and older.

23 See: How the Government Measures Unemployment - Bureau of Labor Statistics, at http://www.bls.gov/cps/cps_htgm.htm. The statistics come from http://www.bls.gov/charts/employment-situation/civilian-unemployment.htm.

24 See: The Employment Situation – Bureau of Labor Statistics, accessed at http://www.bls.gov/news.release/pdf/empsit.pdf.

25 See the statistics at http://www.bls.gov/charts/employment-situation/persons-not-in-the-labor-force-selected-indicators.htm.

26 See: Reports, Trends & Statistics - American Trucking Associations, accessed at http://www.trucking.org/News_and_Information_Reports_Industry_Data.aspx

27 See: Tons of trucking jobs ... that nobody wants - CNN Money, accessed at http://money.cnn.com/2012/07/24/news/economy/trucking-jobs/index.htm.

28 See Varian (2009).

29 See Traufetter (2009) and Thompson (2013).

30 See Thompson (2013).

31 See Nordhaus (2005).

32 See job openings statistics at http://www.bls.gov/opub/ted/2017/job-openings-rose-to-6-point-2-million-in-june-2017.htm.

33 See civilian unemployment statistics at http://www.bls.gov/charts/employment-situation/civilian-unemployment.htm.

34 http://www.bls.gov/news.release/jolts.nr0.htm

35 http://www.bls.gov/opub/ted/2017/job-openings-rose-to-6-point-2-million-in-june-2017.htm

36 See Brynjolfsson and McAfee (2014).

37 *Ibid.*

38 See Katz and Krueger (2016).

39 See Mulcahy (2016a, b). 40 See: The Employment Situation – Bureau of Labor Statistics, accessed at http://www.bls.gov/news.release/pdf/empsit.pdf..

41 OECD, Working Age Population: Aged 15-64: All Persons for the United States - Federal Reserve Bank of St. Louis, accessed at http://fred.stlouisfed.org/series/LFWA64TTUSM647S on August 20, 2017.

42 See McKinsey Global Institute (2016) and Mulcahy (2016a).

43 See Mulcahy (2016a).

44 See Mulcahy (2016a).

45 See Mulcahy (2016a) and Future Workplace and Field Nation (2016).

46 See Mulcahy (2016a).

47 See Autor (2015).

48 See Goos and Manning (2003).

49 See Autor (2015).

50 See, for instance: DC security robot quits job by drowning itself in a fountain - The Verge, accessed at http://www.theverge.com/tldr/2017/7/17/15986042/dc-security-robot-k5-falls-into-water on August 20, 2017.

51 See Autor (2015).

52 Only about 13.4% of job losses in manufacturing have been a result of direct imports or import substitutions (Hicks and Devaraj, 2017). The rest have been due to the increased productivity brought about by automation (ibid). Indeed, even in China, factory workers such as in Foxconn have been replaced by machines (Davenport and Kirby, 2016).

53 See OECD (2017).

54 *Ibid.*

55 *Ibid.*

56 See Autor (2015).

57 See Davenport and Kirby (2016) and Autor (2015).

58 See Bresnahan, Brynjolfsson, and Hitt (2002) and Brynjolfsson and Saunders (2010).

59 See Autor (2015) and OECD (2017).

60 For a discussion on how job polarization has affected wages, see Autor (2015).

61 See Autor (2016).

62 Ibid.

63 See Autor (2015).

64 See Brynjolfsson and McAfee (2014).

65 See Autor (2015) and Davenport and Kirby (2016).

66 *Ibid.*

67 See Davenport and Kirby (2016).

68 *Ibid.*

69 See Brynjolfsson and McAfee (2014) and Davenport and Kirby (2016).

70 See Autor (2015).

71 See Autor (2014).

72 See Bernstein and Raman (2015).

73 See Autor (2015).

74 See Brynjolfsson and McAfee (2014) and Davenport and Kirby (2016).

75 See Gabor (1963).

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