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**THE SECOND  
MACHINE AGE**

Work, Progress, and Prosperity  
in a Time of Brilliant Technologies

2016

authors make a compelling case, and when they turn their attention to America's current condition, they offer important insights and cautions:

Prosperity depends on innovation, and we waste our innovative potential if we do not provide a level playing field for all: we don't know where the next Microsoft, Google, or Facebook will come from, and if the person who will make this happen goes to a failing school and cannot get into a good university, the chances that it will become a reality are much diminished....

The U.S. generated so much innovation and economic growth for the last two hundred years because, by and large, it rewarded innovation and investment. This did not happen in a vacuum; it was supported by a particular set of political arrangements—inclusive political institutions—which prevented an elite or another narrow group from monopolizing political power and using it for their own benefit and at the expense of society.

So here is the concern: economic inequality will lead to greater political inequality, and those who are further empowered politically will use this to gain greater economic advantage, stacking the cards in their favor and increasing economic inequality still further—a quintessential vicious circle. And we may be in the midst of it.<sup>12</sup>

Their analysis hits on a final reason to be concerned about the large and growing inequality of recent years: it could lead to the creation of extractive institutions that would slow our journey into the second machine age. We think this would be something more than a shame; it would be closer to a tragedy. We also believe, based on the work of Acemoglu and Robinson and others, that it is a plausible scenario. Instead of being confident that the bounty from technology will more than compensate for the spread it generates, we

are instead concerned about something close to the reverse: that the spread could actually reduce the bounty in years to come.

### Technological Unemployment

We've seen that the overall pie of the economy is growing, but some people, even a majority of them, can be made worse off by advances in technology. As demand falls for labor, particularly relatively unskilled labor, wages fall. But can technology actually lead to unemployment?

We're not the first people to ask these questions. In fact, they've been debated vigorously, even violently, for at least two hundred years. Between 1811 and 1817, a group of English textile workers whose jobs were threatened by the automated looms of the first Industrial Revolution rallied around a perhaps mythical, Robin Hood-like figure named Ned Ludd and attacked mills and machinery before being suppressed by the British government.

Economists and other scholars saw in the Luddite movement an early example of a broad and important new pattern: large-scale automation entering the workplace and affecting people's wage and employment prospects. Researchers soon fell into two camps. The first and largest argued that while technological progress and other factors definitely cause some workers to lose their jobs, the fundamentally creative nature of capitalism creates other, usually better, opportunities for them. Unemployment, therefore, is only temporary and not a serious problem. John Bates Clark (after whom the medal for the best economist under the age of forty is named) wrote in 1915 that "In the actual [economy], which is highly dynamic, such a supply of unemployed labor is always at hand, and it is neither possible [nor] normal that it should be altogether absent. The well-being of workers requires that progress should go on, and it cannot do so without causing temporary displacement of laborers."<sup>13</sup>

The following year, the political scientist William Leiserson took this argument further. He described unemployment as something close to a mirage: "the army of the unemployed is no more unemployed than are firemen who wait in fire-houses for the alarm to sound, or the reserve police force ready to meet the next call."<sup>14</sup> The creative forces of capitalism, in short, required a supply of ready labor, which came from people displaced by previous instances of technological progress.

John Maynard Keynes was less confident that things would always work out so well for workers. His 1930 essay "Economic Possibilities for our Grandchildren," while mostly optimistic, nicely articulated the position of the second camp—that automation could in fact put people out of work permanently, especially if more and more things kept getting automated. His essay looked past the immediate hard times of the Great Depression and offered a prediction: "We are being afflicted with a new disease of which some readers may not yet have heard the name, but of which they will hear a great deal in the years to come—namely, *technological unemployment*. This means unemployment due to our discovery of means of economizing the use of labor outrunning the pace at which we can find new uses for labor."<sup>15</sup> The extended joblessness of the Great Depression seemed to confirm Keynes's ideas, but it eventually eased. Then came World War II and its insatiable demands for labor, both on the battlefield and the home front, and the threat of technological unemployment receded.

After the war ended, the debate about technology's impact on the labor force resumed and took on new life once computers appeared. A commission of scientists and social theorists sent an open letter to President Lyndon Johnson in 1964 arguing that:

A new era of production has begun. Its principles of organization are as different from those of the industrial era as those of the industrial era were different from the agricultural. The cybernation revolution has been brought about by the com-

blination of the computer and the automated self-regulating machine. This results in a system of almost unlimited productive capacity which requires progressively less human labor.<sup>16</sup>

The Nobel Prize-winning economist Wassily Leontief agreed, stating definitively in 1983 that "the role of humans as the most important factor of production is bound to diminish in the same way that the role of horses in agricultural production was first diminished and then eliminated by the introduction of tractors."<sup>17</sup>

Just four years later, however, a panel of economists assembled by the National Academy of Sciences disagreed with Leontief and made a clear, comprehensive, and optimistic statement in their report "Technology and Employment":

By reducing the costs of production and thereby lowering the price of a particular good in a competitive market, technological change frequently leads to increases in output demand; greater output demand results in increased production, which requires more labor, offsetting the employment effects of reductions in labor requirements per unit of output stemming from technological change. . . . Historically and, we believe, for the foreseeable future, reductions in labor requirements per unit of output resulting from new process technologies have been and will continue to be outweighed by the beneficial employment effects of the expansion in total output that generally occurs.<sup>18</sup>

This view—that automation and other forms of technological progress in aggregate create more jobs than they destroy—has come to dominate the discipline of economics. To believe otherwise is to succumb to the "Luddite Fallacy." So in recent years, most of the people arguing that technology is a net job destroyer have not been mainstream economists.

The argument that technology cannot create ongoing structural

unemployment, rather than just temporary spells of joblessness during recessions, rests on two pillars: 1) economic theory and 2) two hundred years of historical evidence. But both of these are less solid than they first appear.

First, the theory. There are three economic mechanisms that are candidates for explaining technological unemployment: inelastic demand, rapid change, and severe inequality.

If technology leads to more efficient use of labor, then as the economists on the National Academy of Sciences panel pointed out, this does not automatically lead to reduced demand for labor. Lower costs may lead to lower prices for goods, and in turn, lower prices lead to greater demand for the goods, which can ultimately lead to an increase in demand for labor as well. Whether or not this will actually happen depends on the elasticity of demand, defined as the percentage increase in the quantity demanded for each percentage decline in price.

For some goods and services, such as automobile tires or household lighting, demand has been relatively inelastic and thus insensitive to price declines.<sup>19</sup> Cutting the price of artificial light in half did not double the amount of light consumers and businesses demanded, so the total revenues for the lighting industry have fallen as lighting became more efficient. In an great piece of historical sleuthing, economist William Nordhaus documented how technology has reduced the price of light by over a thousand-fold since the days of candles and whale oil lamps, allowing us to expend far less on labor while getting all the light we need.<sup>20</sup> Whole sectors of the economy, not just product categories, can face relatively inelastic demand. Over the years agriculture and manufacturing have each experienced falling employment as they became more efficient. The lower prices and improved quality of their outputs did not lead to enough increased demand to offset improvements in productivity.

On the other hand, when demand is very elastic, greater productivity leads to enough of an increase in demand that more labor ends up

employed. The possibility of this happening for some types of energy has been called the Jevons paradox: more energy efficiency can sometimes lead to greater total energy consumption. But to economists there is no paradox, just an inevitable implication of elastic demand.

This is especially common in new industries like information technology.<sup>21</sup> If elasticity is exactly equal to one (i.e., a 1 percent decline in price leads to exactly a 1 percent increase in quantity), then total revenues (price times quantity) will be unchanged. In other words, an increase in productivity will be exactly matched by an identical increase in demand to keep everyone just as busy as they were before.

Elasticity of exactly one might seem like a very special case, yet a good (but not airtight) argument can be made that, in the long run, this is exactly what happens in the overall economy. For instance, falling food prices might reduce demand for agricultural labor, but they free up just enough money to be spent elsewhere in the economy so that overall employment is maintained.<sup>22</sup> The money is spent not just buying more of the existing goods, but also on newly invented products and services. This is the core of the economic argument that technological unemployment is impossible.

KEYNES DISAGREED. He thought that in the long run, demand would not be perfectly inelastic. That is, ever lower (quality-adjusted) prices would not necessarily mean we would consume ever more goods and services. Instead, we would become satiated and choose to consume less. He predicted that this would lead to a dramatic reduction in working hours to as few as fifteen per week as less and less labor was needed to produce all the goods and services that people demanded.<sup>23</sup> However, it's hard to see this type of technological unemployment as an economic problem. After all, in that scenario, by definition, people are working less because they are satiated. The "economic problem" of scarcity is replaced by the entirely more appealing problem of what to do with abundant wealth and copious

leisure. As Arthur C. Clarke is purported to have put it, "The goal of the future is full unemployment, so we can play."<sup>24</sup>

Keynes was more concerned with short-term "maladjustments," which brings us to the second, more serious argument for technological unemployment: the inability of our skills, organizations, and institutions to keep pace with technical change. When technology eliminates one type of job, or even the need for a whole category of skills, those workers will have to develop new skills and find new jobs. Of course, that can take time, and in the meantime they may be unemployed. The optimistic argument maintains that this is temporary. Eventually, the economy will find a new equilibrium and full employment will be restored as entrepreneurs invent new businesses and the workforce adapts its human capital.

But what if this process takes a decade?<sup>25</sup> And what if, by then, technology has changed again? This is the possibility that Wasily Leontief had in mind his 1983 article when he speculated that many workers could end up permanently unemployed, like horses unable to adjust to the invention of the tractor.<sup>26</sup> Once one concedes that it takes time for workers and organizations to adjust to technical change, then it becomes apparent that accelerating technical change can lead to widening gaps and increasing possibilities for technological unemployment. Faster technological progress may ultimately bring greater wealth and longer lifespans, but it also requires faster adjustments by both people and institutions. With apologies to Keynes, in the long run we may not be dead, but we will still need jobs.

The third argument for technological unemployment may be the most troubling of all. It goes beyond "temporary" maladjustments. As described in detail in chapters 8 and 9, recent advances in technology have created both winners and losers via skill-biased technical change, capital-biased technical change, and the proliferation of superstars in winner-take-all markets. This has reduced the demand for some types of work and skills. In a free market, prices adjust to

restore equilibrium between supply and demand, and indeed, real wages have fallen for millions of people in the United States.

In principle, the equilibrium wage could be one dollar an hour for some workers, even as other workers command a wage thousands of times higher. Most people in advanced countries would not consider one dollar an hour a living wage, and don't expect society to require people to work at that wage under threat of starvation. What's more, in extreme winner-take-all markets, the equilibrium wage might be zero: even if we offered to sing "Satisfaction" for free, people would still prefer to pay for the version sung by Mick Jagger. In the market for music, Mick can now, in effect, make digital copies of himself that compete with us. A near-zero wage is not a living wage. Rational people would rather look for another gig, and look, and look, and look, than depend on a near-zero wage for their sustenance.

Thus, there is a floor on how low wages for human labor can go. In turn, that floor can lead to unemployment: people who want to work, but are unable to find jobs. If neither the worker nor any entrepreneur can think of a profitable task that requires that worker's skills and capabilities, then that worker will go unemployed indefinitely. Over history, this has happened to many other inputs to production that were once valuable, from whale oil to horse labor. They are no longer needed in today's economy even at zero price. In other words, just as technology can create inequality, it can also create unemployment. And in theory, this can affect a large number of people, even a majority of the population, and even if the overall economic pie is growing.

So that's theory, but what about the data? For most of the two hundred years since the Luddite rebellion technology has boosted productivity enormously, but the data show that employment grew alongside productivity up until the end of the twentieth century. This shows that productivity doesn't always lead to job destruction. It's even tempting to suppose that productivity somehow inevita-

by leads to job creation, as technology boosters sometimes argue. However, as we saw in figure 11.1, the data also show that, more recently, job growth decoupled from productivity in the late 1990s. According to Jared Bernstein, the anti-Luddites call this fact a "head scratcher." Which history should we take guidance from: the two centuries ending in the late 1990s, or the fifteen years since then? We can't know for sure, but our reading of technology tells us that the power of exponential, digital, and combinatorial forces, as well as the dawning of machine intelligence and networked intelligence, presage even greater disruptions.

### The Android Experiment

Imagine that tomorrow a company introduced androids that could do absolutely everything a human worker could do, including building more androids. There's an endless supply of these robots, and they're extremely cheap to buy and virtually free to run over time. They work all day, every day, without breaking down.

Clearly, the economic implications of such an advance would be profound. First of all, productivity and output would skyrocket. The androids would operate the farms and factories. Food and products would become much cheaper to produce. In a competitive market, in fact, their prices would fall close to the cost of their raw materials. Around the world, we'd see an amazing increase in the volume, variety, and affordability of offerings. The androids, in short, would bring great bounty.

They'd also bring severe dislocations to the labor force. Every economically rational employer would prefer androids, since compared to the status quo they provide equal capability at lower cost. So they would very quickly replace most, if not all, human workers. Entrepreneurs would continue to develop novel products, create new markets, and found companies, but they'd staff these companies with androids instead of people. The owners of the androids and other

capital assets or natural resources would capture all the value in the economy, and do all the consuming. Those with no assets would have only their labor to sell, and their labor would be worthless.

This thought experiment reflects the reality that there is no 'iron law' that technological progress must always be accompanied by broad job creation.

One slight variation on this thought experiment imagines that the androids can do everything a human worker can do except for one skill—say, cooking. The economic results would be unchanged, except that there would still be human cooks. Because there would be so much competition for these jobs, however, companies that employed cooks could offer much lower wages and still fill their open positions. The total number of hours spent cooking in the economy would stay the same (at least as long as people kept eating in restaurants), but the total wages paid to cooks would go down. The only exception might be superstar chefs with some combination of skill and reputation that could not be duplicated by other people. Superstars would still be able to command high wages; other cooks would not. So in addition to bringing great bounty of output, the androids would also greatly increase the spread in income.

How useful are these thought experiments, which sound more like science fiction than any current reality? Fully functional humanoid androids are not rumbling around at American companies today. In fact, they don't yet exist, and until recently progress had been slow in making machines that can take the places of human workers in areas like pattern recognition, complex communication, sensing, and mobility. But as we've seen, the pace of progress here has been accelerating greatly in recent years.

The better machines can substitute for human workers, the more likely it is that they'll drive down the wages of humans with similar skills. The lesson from economics and business strategy is that you don't want to compete against close substitutes, especially if they have a cost advantage.

But in principle, machines can have very different strengths and weaknesses than humans. When engineers work to amplify these differences, building on the areas where machines are strong and humans are weak, then the machines are more likely to *complement* humans rather than substitute for them. Effective production is more likely to require both human and machine inputs, and the value of the human inputs will grow, not shrink, as the power of machines increases. A second lesson of economics and business strategy is that it's great to be a complement to something that's increasingly plentiful. Moreover, this approach is more likely to create opportunities to produce goods and services that could never have been created by unaugmented humans, or machines that simply mimicked people, for that matter. These new goods and services provide a path for productivity growth based on increased output rather than reduced inputs.

Thus in a very real sense, as long as there are unmet needs and wants in the world, unemployment is a loud warning that we simply aren't thinking hard enough about what needs doing. We aren't being creative enough about solving the problems we have using the freed-up time and energy of the people whose old jobs were automated away. We can do more to invent technologies and business models that augment and amplify the unique capabilities of humans to create new sources of value, instead of automating the ones that already exist. As we will discuss further in the next chapters, this is the real challenge facing our policy makers, our entrepreneurs, and each of us individually.

### An Alternative Explanation: Globalization

Technology isn't the only thing transforming the economy. The other big force of our era is globalization. Could this be the reason that median wages have stagnated in the United States and other advanced economies? A number of thoughtful economists have made exactly that argument. The story is one of *factor price equalization*.

\* Automation ~~is~~ <sup>is</sup> ~~reducing~~ <sup>reducing</sup> American ~~and Chinese workers~~ <sup>and Chinese workers</sup> wages

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This means that in any single market, competition will tend to bid the prices of the factors of production—such as labor or capital—to a single, common price.\* Over the past few decades, lower transaction in communication costs have helped create one big global market for many products and services.

Businesses can identify and hire workers with skills they need anywhere in the world. If a worker in China can do the same work as an American, then what economists call “the law of one price” demands that they earn essentially the same wages, because the market will arbitrage away differences just as it would for other commodities. That's good news for the Chinese worker, and for overall economic efficiency. But is not good news for the American worker who now faces low-cost competition. A number of economists have made exactly this argument. Michael Spence, in his brilliant book *The Next Convergence*, explains how the integration of global markets is leading to enormous dislocations, especially in labor markets.<sup>27</sup>

The factor price equalization story yields a testable prediction: American manufacturers would be expected to shift production overseas, where costs are lower. And indeed manufacturing employment in the United States has fallen over the past twenty years; economists David Autor, David Dorn, and Gordon Hanson estimate that competition from China can explain about a quarter of the decline in U.S. manufacturing employment.<sup>28</sup> However, when one looks more closely at the data, the globalization story becomes much less compelling. Since 1996, manufacturing employment in China itself has actually fallen as well, coincidentally by an estimated 25 percent.<sup>29</sup> That's over thirty million fewer Chinese workers in that sector, even while output soared by 70 percent. It's not that American workers are being replaced by Chinese workers. It's that both American and

\* This is no different from the concept we invoked when we were comparing and equating the wages of human workers with robots that, hypothetically, had identical capabilities.

*Foxconn automating its factories -  
as this new strategy leads to the  
moved work to the North.*

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Chinese workers are being made more efficient by automation. As a result, both countries are producing more output with fewer workers.

In the long run, the biggest effect of automation is likely to be on workers not in America and other developed nations, but rather in developing nations that currently rely on low-cost labor for their competitive advantage. If you take most of the costs of labor out of the equation by installing robots and other types of automation, then the competitive advantage of low wages largely disappears. This is already beginning to happen. Terry Guo of Foxconn has been aggressively installing hundreds of thousands of robots to replace an equivalent number of human workers. He says he plans to buy millions more robots in the coming years. The first wave is going into factories in China and Taiwan, but once an industry becomes largely automated, the case for locating a factory in a low-wage country becomes less compelling. There may still be logistical advantages if the local business ecosystem is strong, making it easier to get spare parts, supplies, and custom components. But over time inertia may be overcome by the advantages of reducing transit times for finished products and being closer to customers, engineers and designers, educated workers, or even regions where the rule of law is strong. This can bring manufacturing back to America, as entrepreneurs like Rod Brooks have been emphasizing.

A similar argument applies outside of manufacturing. For instance, interactive voice-response systems are automating jobs in call centers. United Airlines has been successful in making such a transition. This can disproportionately affect low-cost workers in places like India and the Philippines. Similarly, many medical doctors used to have their dictation sent overseas to be transcribed. But an increasing number are now happy with computer transcription. In more and more domains, intelligent and flexible machines, not humans in other countries, are the most cost-effective source for 'labor.'

If you look at the types of tasks that have been offshored in the past twenty years, you see that they tend to be relatively routine,

well-structured tasks. Interestingly, these are precisely the tasks that are easiest to automate. If you can give precise instructions to someone else on exactly what needs to be done, you can often write a precise computer program to do the same task. In other words, offshoring is often only a way station on the road to automation.

In the long run, low wages will be no match for Moore's Law. Trying to fend off advances in technology by cutting wages is only a temporary protection. It is no more sustainable than asking folk legend John Henry to lift weights to better compete with a steam-powered hammer.