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# INTRODUCTION

Progress would be wonderful—if only it would stop.

—ROBERT MUSIL

When looms weave by themselves, man's slavery will end.

—ARISTOTLE

Had it not been for the deeds of six hundred lamplighters, the streets of New York City at night in 1900 would have been lit by nothing but the moon. Equipped with torches and ladders, they were the force ensuring that pedestrians could see more than a burning cigar a block off when they left their homes. But on the night of April 24, 1907, most of the twenty-five thousand gas lights in the streets of Manhattan were never lit. The lamplighters, who would normally start carrying the torch of civilization around 6:50 P.M., left the lights out and went on strike. No violence was reported. But as it grew darker, New Yorkers poured in complaints to the gas companies and the local police. Policemen were sent in to light up the neighborhoods, yet without ladders this proved a difficult task. Many officers were too obese to climb the lampposts. And they got little help from the public. In Harlem, crowds of boys invented a new sport: whenever an officer was successful in firing up a lamp, they would climb the post, turn out the light, and run. On Park Avenue one youngster was arrested after having put a light out after an

officer got it burning. Few lamps burned for long. Even by 9:00 P.M., the only bright public spots were a few transverse roads in Central Park, which had been equipped with electric streetlights.[1]

Citizens who took up work as lamplighters that year were unlucky. Oil and gas lamps had always required personal attention, but with the mysterious force of electricity, the touch of the lamplighter was no longer a skill that had any value. Electric streetlights brought light and nostalgia. Many citizens still felt that a young man must turn lights on at dusk and off at dawn. In New York City, lamplighters had become a neighborhood institution alongside the police and the postman. Their profession had existed since the first streetlights were inaugurated in London in 1414, but it was about to become a distant memory. As the *New York Times* noted in 1924, "The lamplighting business in the great metropolis has been victim of too much progress."[2] To be sure, the first electric streetlights in New York City had already been installed in the late nineteenth century, but they had hardly made lamplighters redundant. Each lamp was equipped with its own switch, which had to be turned on manually. Early electrification just made the job easier, as lamplighters no longer had to carry long torches to ignite the lamps. Still, the men who used to light the gas lamps were not the beneficiaries of progress. The mastery of light had once allowed a working man to support his family. Now, turning on the lights had become a task so simple that it could be done by young boys on their way home from school. And as so often in history, simplification was merely a step toward automation. As electric streetlights were increasingly regulated from substations, the jobs of lamplighters were cut in large numbers. By 1927, electricity had a monopoly on illumination in New York City, and the last two gas lamplighters left their craft, ending the story of their profession and that of the Lamplighters Union.[3]

Thomas Edison's invention of the light bulb surely made the world better and brighter. In his laboratory in Menlo Park, oil lamps and candles still polluted the air on the day of his breakthrough. As William Nordhaus, winner of the Nobel Prize in Economics in 2018, has shown, the price of light fell dramatically thereafter, as electricity spread to Chicago's Academy of Music, London's House of Commons, Milan's La

Scala, and the trading floor of the New York Stock Exchange.[4] For the purpose of streetlighting, even the New York lamplighters, some of whom were forced into early retirement, willingly admitted that the new system was more expeditious. One lamplighter could at best attend to some fifty lamps per night. Now, several thousand lamps could be switched on by one substation employee in seconds. Yet nothing could be more natural than resisting a threat to one's livelihood. For most citizens, their skills are their capital, and it is from that human capital that they derive their subsistence. Thus, despite all the virtues of the new system, it is not surprising that electric light wasn't welcomed by everyone everywhere. When the municipality of Verviers in Belgium announced the switch to electricity, for example, lamplighters took to the streets in fear of losing their jobs. To banish the tyranny of darkness, the local government enrolled another team of lamplighters, but they were soon attacked by the strikers—who threatened to keep breaking lamps till doomsday. Intervention by local police ended with angry lamplighters raiding police headquarters. The Belgian government had to call in the army to resolve the situation.[5]

Some surely paid the price for progress. But over the course of the twentieth century, the vast majority of citizens in the West have accepted technology as the engine of their fortunes. They have recognized that it improved working conditions by eliminating the most hazardous and servile jobs. They realized that their wages depended on the use of mechanical power. And they benefited from the continuous flow of new goods and services that became available to them. Revolutionary technologies like automobiles, refrigerators, radios, and telephones—to name just a few—were all unavailable to European monarchs in the Renaissance, but by 1950 they were common features of Western life. In 1900, the average housewife could still only dream of living like the upper classes, who had servants to do the most tedious household tasks for them. In the following decades every home suddenly got equal access to the electric servant. Washing machines, electric irons, and a host of other electric appliances took over hours of drudgery in the home. In short, the capitalist achievement, as the great economist Joseph Schumpeter observed, did not consist of providing "more silk stockings for

queens but in bringing them within the reach of factory girls in return for steadily decreasing amounts of effort."[6]

It is easy to oversimplify history. However, if there is one predominant factor underlying economic and social change over the past two centuries, it is surely the advancement of technology. Without technological change, "capital accumulation would amount to piling wooden plows on top of wooden plows," to borrow Evsey Domar's phrase.[7] Economists estimate that over 80 percent of the income differences between rich and poor countries can be explained by differential rates of technology adoption.[8] And relying on income alone hugely understates the transformation that has taken place. It is quite extraordinary to think that in the world my great-grandmother was born into, people could not travel faster than horses or trains could carry them. The only escape from darkness during night was the candle and the oil lamp. Jobs were physically demanding. Few women did paid work. The home was the woman's workplace, where meals were prepared on an open hearth, and trees had to be chopped down for fuel to cook with and keep the house warm. And buckets of water had to be carried indoors from a stream or well. Unsurprisingly, people felt much enthusiasm for progress, not to say euphoria. A 1915 article published in *Literary Digest* confidently predicted that with electrification, it "will become next to impossible to contract disease germs or get hurt in the city, and country folk will go to town to rest and get well."[9] Edison himself was convinced that electricity would help us overcome the greatest hurdle to further progress: our need to sleep. Technology was the new religion of the people. There was the sense that there was no problem that technology could not solve.

In hindsight, and in the light of the gains brought by technology, it is astounding to think that economists of the early nineteenth century like Thomas Malthus and David Ricardo did not believe that technology could improve the human lot. The technological virtuosity of the nineteenth and early twentieth centuries took some time to trickle down to the economics profession. But in the 1950s, Robert Solow, who would go on to win the Nobel Prize in Economics in 1987, found that virtually all economic advance over the twentieth century had been thanks to technology. And others documented that those gains had been widely

shared. Simon Kuznets found that America had become more equal and advanced his theory of capitalist development in which inequality automatically decreases along the industrialization path. Nicholas Kaldor observed that labor had consistently reaped about two-thirds of the gains of growth. And Solow developed a theoretical framework in which progress delivered equal benefits for every social group around that time. Seen through the lens of today, such optimism might seem absurd. But the economist of the 1950s had much to be optimistic about.

What do the jobs of a few lamplighters matter if society as a whole can become both richer and more equal simply by letting technological creativity thrive? Many displaced lamplighters probably even found less hazardous and better-paying jobs. And even if some lost out to technology, it seems right that society willingly accepted progress for the many at the expense of the few. But would we feel that way if the victims of progress had been more plentiful? What if the majority of replaced workers were forced to move into jobs that paid less well? After all, the "special century" was not just special in that it excelled in economic growth.[10] Just as important was the fact that almost everyone gained from progress. While there were clearly labor-replacing technologies, most were of the enabling sort. Overall, technology served to make workers more productive and their skills more valuable, allowing them to earn better wages. And even those who lost their jobs to the force of mechanization had a greater abundance of less physically demanding and better-paying jobs to choose from as a consequence. In the age of artificial intelligence (AI), as this book will argue, such optimism about technology can no longer be taken for granted. Nor has it been the historical norm. Economists of the golden age were right to be optimistic about the time in which they lived. Their mistake was in thinking that what they witnessed would continue indefinitely. There is no iron law that postulates that technology must benefit the many at the expense of the few. And quite naturally, when large swaths of the populace are left behind by technological change, they are likely to resist it.

The price of progress has varied greatly throughout history. Simplifications of human advancement like figure 1, which are often used to illustrate the great leap forward, miss all the action. The point is not that the figure is incorrect. It rightly shows that per capita growth in gross domestic product (GDP) was stagnant for millennia and took off in an extraordinary fashion around 1800. Thus, tracking progress purely in terms of average incomes leads one to conclusions like this one: "Modern humans first emerged about 100,000 years ago. For the next 99,800 years or so, nothing happened. . . . Then—just a couple of hundred years ago—people started getting richer. And richer and richer still. Per capita income, at least in the West, began to grow at the unprecedented rate of about three quarters of a percent per year. A couple of decades later, the same thing was happening around the world. Then it got even better."[11]

This standard narrative is unfortunate. Because of it, we often forget that during the extraordinary upward trend in growth that began in eighteenth-century England, millions of people were adjusting to change. And some had more cheerful stories than others. There were even those who would have been better off had mechanization not been allowed to progress. Figure 1 leads us to think that everyone living today must be better off than the previous generation, just as the generation born in 1800 must have seen staggering improvements in their living standards relative to those of their grandparents. Figure 1 also suggests that we were not very inventive before the eighteenth century. Otherwise, why would growth have been so slow? Yet a closer examination of preindustrial times reveals some pathbreaking inventions and ideas. And if we zoom into different episodes of progress, as this book will, we find that people fared very differently in the winds of change.

The "takeoff" depicted in figure 1 began with the arrival of the mechanized factory. Italy could take some credit for its inception. Drawings of the silk-throwing machines that led to the first factories came from Piedmont through an episode of industrial espionage for which Thomas Lombe received a knighthood from the British government. But England was first to exploit machinery on a mass scale. Indeed, while the Industrial Revolution had its origins in silk production, its true

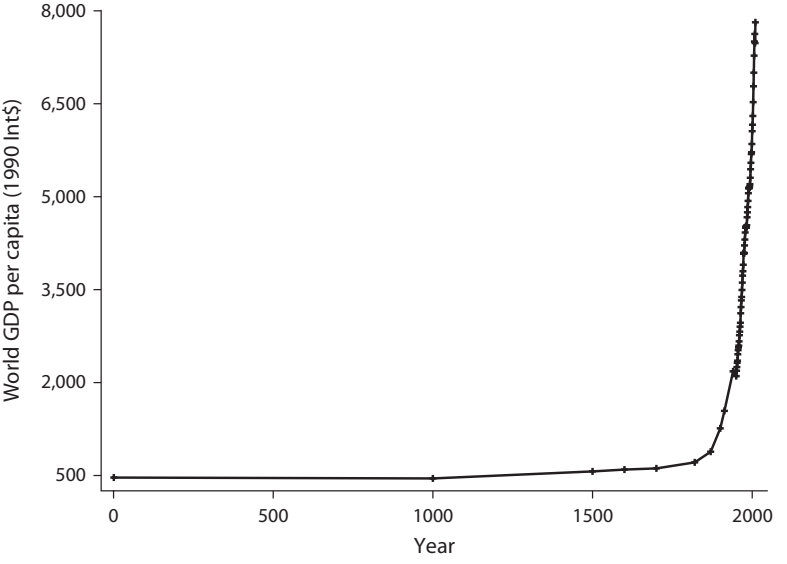


FIGURE 1: World Gross Domestic Product per Capita, 1–2008
*Source: J. Bolt, R. Inklaar, H. de Jong, and J. L. Van Zanden, 2018, "Rebasing 'Maddison': New Income Comparisons and the Shape of Long-Run Economic Development," Maddison Project Working Paper 10, Maddison Project Database, version 2018.*

beginnings were in the cotton industry. As the historian Eric Hobsbawm famously remarked, "Whoever says Industrial Revolution says cotton."[12] After the mechanization of cotton production, change begat change as a self-reinforcing cascade of progress created the modern world. As technology progressed in the early days of industrialization, however, living standards for many regressed. Our vocabulary bears witness to the changes that signify the century after 1750. Words like "factory," "railroad," "steam engine," and "industry" first emerged then. But so did "working class," "communism," "strike," "Luddite," and "pauperism." What began with the arrival of the first factories ended not only with the construction of the railroads, but also with the publication of the *Communist Manifesto*. Just as the Industrial Revolution was responsible for many revolutionary technologies, so it was responsible for many political revolutionaries along the way.[13]

The point is not to downplay the significance of the British Industrial Revolution. It is rightly regarded as the main event in human history because it eventually allowed humanity to escape the life that Thomas Hobbes described as "nasty, brutish, and short."[14] Eventually was nonetheless a long time. The "Great Escape," as the economist Angus Deaton has called it, didn't immediately turn the cottage of the commoner into a Garden of Eden.[15] During the early days of industrialization, the lives of many commoners got nastier, more brutish, and shorter. Material standards and living conditions for the masses in Britain failed to improve before 1840. The poet William Blake's phrase "dark, satanic mills" captures the long working hours in the factories and the hazardous conditions that embodied the industrialization process.[16] In major industrial cities like Manchester and Glasgow, life expectancy at birth was some staggering ten years shorter than the national average. The wages that workers took home in industrial cities hardly compensated for the dirty and unhealthy conditions in which people lived and worked. Although output expanded, the gains from growth didn't find their way into the pockets of ordinary people. Real wages were stagnant or even falling for some. The only thing workers saw expanding was the number of hours spent in the "dark, satanic mills." The gains of progress overwhelmingly went to industrialists, who saw their rate of profit double. Consequently, the average amount of food consumed in Britain during the Industrial Revolution did not increase until the 1840s. The share of households with a surplus for nonessentials declined among low-wage agricultural laborers and factory workers over the first half of the nineteenth century. And poor nutrition meant that people grew shorter by the generation. These were the glorious decades in which modern growth began.[17]

The cause of the living standards crisis in Britain was the downfall of the domestic system of production, which was gradually displaced by the mechanized factory. Artisan craftsmen were highly skilled and earned decent wages. But with the rise of the factory, one artisan after another saw his income vanish. And while new jobs were created in the factories, spinning machines were specifically designed for children, who could do the job for a fraction of the cost of adults and thus became a growing share of the workforce. They were the robots of the Industrial

Revolution. Besides working for very little, they did not have any bargaining power and were easy to control.[18]

As the old artisanal skills were made obsolete by advances in mechanization, adult male workers lost out: the share of children workers rapidly expanded, reaching about half of the workforce employed in textiles during the 1830s. The social costs inflicted upon the workforce—including vanishing incomes, deteriorating health and nutrition, forced occupational and geographical migration, and in some cases unemployment—were not negligible. Not to mention the suffering of children. In an interview, Robert Blincoe, a former child laborer, stated that he would rather have his children deported to Australia than let them experience life working in the factories.[19] But from a purely economic point of view, adult artisans were without question the prime victims of industrialization. And there were many of them. As one leading scholar of the Industrial Revolution, David Landes, writes, "If mechanization opened new vistas of comfort and prosperity for all men, it also destroyed the livelihood of some and left others to vegetate in the backwaters of the stream of progress. . . . The victims of the Industrial Revolution numbered in the hundreds of thousands or even millions."[20]

Historians have puzzled over why ordinary English people would voluntarily agree to take part in an industrialization process that reduced their living standards. The simple answer is that they didn't. British governments at times clashed with workmen raging against the machine. But their efforts were unsuccessful, as British governments took an increasingly stern view of anything that might diminish England's competitive position in trade. All the Luddites achieved during the risings of 1811–16 is prompting the government to deploy an even larger army against them: the twelve thousand troops sent to resolve the machinery riots amounted to more people than the army Wellington took into the Peninsular War against Napoleon in 1808.

As we shall see, before the late nineteenth century, resistance to technologies that threatened workers' skills was the rule rather than the exception. While much commentary tends to focus on the Luddite riots, they were just part of a long wave of riots that swept across Europe and China. And the history of opposition to labor-replacing technologies

goes back much further. Vespasian, the emperor of Rome in 69–79, refused to adopt machinery for transporting columns to the Capitoline Hill due to employment concerns. And in 1589, Elizabeth I famously refused to grant William Lee a patent for his stocking-frame knitting machine, fearing unemployment as a result of the technological advance. The gig mill, which saved considerable amounts of labor, had been prohibited in Britain in 1551. And elsewhere in Europe opposition was just as fierce. Many European cities banned automatic looms in the seventeenth century. Why? Where they were adopted (for example, in the city of Leiden), riots followed. The ruling classes feared that angry workers like those in Leiden would start to rebel against the government. And this concern was by no means just European. One reason why China was so late to industrialize, economic historians have argued, is that resistance to technologies that threatened workers' skills persisted up until the closing decades of the nineteenth century, when imported sewing machines were destroyed by native workers. In fact, the British government was the first to side with the pioneers of industry rather than rebelling workers, providing one explanation for why Britain was the first country to industrialize.[21]

Back in 2012, Bill Gates took note of what has been called the paradox of our age: "Innovation is faster than ever before . . . yet Americans are more pessimistic about the future."[22] Indeed, according to the Pew Research Center, just over a third of Americans still believe that their children will be better off financially than they were.[23] If the past few decades are any guide to the future, some people surely have much to be pessimistic about. Only half of Americans born in 1980 are economically better off than their parents, compared to 90 percent of those born in 1940.[24] Despite this fact, slogans like "the greatest country on earth" continued to be the norm in presidential election campaigns. It was only in 2016 that the Republican presidential candidate won with the slogan "Make America Great Again." At last a candidate spoke the truth—or

so it must have felt in those parts of the country where opportunities had long since faded.

As the Industrial Revolution illustrates, the Gates paradox is not really a paradox. Like in the early days of industrialization, workers today are no longer reaping the gains of progress. Worse, many have been left behind in the backwaters of progress. In the same way that opportunity dried up for middle-income artisans as a consequence of the industrialization process, the age of automation has meant diminishing opportunities for the American middle class. Like the victims of the early factories, many Americans have adjusted to the computerization of work by unwillingly shifting into lower-paying jobs or have failed to adjust and dropped out of the workforce completely. And similar to the victims of the factories, the losers to automation have primarily been men in the prime of life. Up until the 1980s, manufacturing jobs allowed ordinary working men to attain a middle-class lifestyle without going to college. As employment opportunities in manufacturing receded, a path of upward mobility was closed to many citizens.[25]

What's more, the adverse consequences of automation have so far primarily been a local phenomenon. Focusing too closely on national statistics disregards the fact that if you put one hand in the freezer and the other on the stove, you should feel quite comfortable on average. The same was true of the Industrial Revolution. While the local cloth industry in Northamptonshire was left in ruins, factories were almost unheard of in 1800 in the pastoral areas of southern England, where Jane Austen resided. This time around, the social and economic fabric has been torn apart in old manufacturing cities, where automation has deprived middle-aged men of opportunity. Communities that have seen manufacturing jobs vanish, due either to automation or globalization, have endured persistent increases in joblessness. They have also seen public services deteriorate, greater increases in property crime and violent crime, and worse health outcomes. They have seen mortality rates increase due to suicide and alcohol-related liver disease. They have seen marriage rates collapse, leaving more children in single-parent households, with dismal future prospects. Rates of social mobility are

significantly lower in places where middle-class jobs have evaporated.[26] And where jobs have disappeared, people have become more likely to vote for populist candidates. Indeed, studies have shown that both in America and in Europe, the appeal of populism has been greater where jobs have become more exposed to automation.[27] Just like the days of the Industrial Revolution, the losers to technology are demanding change.

We should have seen it coming. In 1965, when the first electronic computers entered offices, Eric Hoffer warned in the *New York Times* that "a skilled population deprived of its sense and usefulness would be the ideal setup for an American Hitler."[28] Perhaps somewhat ironically, Hitler and his government were well aware of the disruptive force of labor-replacing technology. His appointment as chancellor of Germany on January 30, 1933, heralded the return of preindustrial policies, which sought to restrict the use of machinery. In Danzig, where the Nazi Party won over 50 percent of the votes that year, such efforts became a major priority. To deal with the issue of technological unemployment, the Senate decreed that machinery would not be installed in factories without special permission of the government. Failure to comply would lead to heavy penalties or even being forced to shut down by the government.[29] In August 1933, Alfred von Hodenberg, leader of the Nazi Labor Front, made clear that machines would not be allowed to threaten workers' jobs in the future. "Never again," he reassured the public, "must the worker be replaced by a machine."[30]

## Technology at Work

Our path to riches is best understood in terms of the adoption of a steady flow of labor-saving technologies over the centuries. As the economist Paul Krugman once quipped, "depressions, runaway inflation, or civil war can make a country poor, but only productivity can make it rich."[31] Productivity growth happens when technology allows us to produce more with less. If the adoption of machines makes labor productivity grow by 2.5 percent per year, output per person will double every twenty-eight years. The notion that the product of an hour of work can double in just about half of a working lifetime is surely sufficient

justification for the disruptive force of technology, which has shrunk that timescale visibly. But while productivity is a prerequisite for growing incomes for the commoner, it is not a guarantee of such growth. And, if machines replace workers in existing functions, some people may be left worse off as technology progresses. Despite this fact, textbook economics treats technological progress as a Pareto improvement: in other words, the assumption is that when machines take workers' jobs, new and better-paying jobs become available for everyone at the same time. As evidenced by the historical record, such models are utterly irrelevant for understanding episodes when technological progress is labor replacing. These technologies have brought higher material standards but also worker dislocation.

The extent to which labor-saving technologies will cause dislocation depends on whether they are enabling or replacing. Replacing technologies render jobs and skills redundant. Enabling technologies, in contrast, make people more productive in existing tasks or create entirely new jobs for them. Thus, the term "labor saving" has two closely associated but not identical meanings, and the difference between the two has important implications for labor.[32] As the economist Harry Jerome noted in 1934, if the 1929 tonnage of iron and steel were produced with the technology available in 1890, a million and a quarter workers would have been needed instead of four hundred thousand. Does this mean that eight hundred thousand men had lost their jobs by 1929? Surely not. At the onset of the Great Depression, employment in steel had grown.[33] Better technology reduced the number of workers required to produce a given amount of steel, but the steadily growing demand for steel meant that the number of jobs in the industry grew, too. Clearly, the nature of steel production changed as the industry mechanized, but there was probably little job displacement. Unlike replacing technologies, which take over the tasks previously done by labor, augmenting technologies increase the units of a worker's output without any displacement occurring, unless demand for a given product or service becomes saturated.[34] There are many examples of enabling technologies. Computer-aided design software has made architects, engineers, and other skilled professionals more productive by helping rather than replacing them.

Statistical computer programs like Stata and Matlab have made statisticians and social scientists better analysts without reducing the demand for them. And office machines like the typewriter created clerical jobs that did not previously exist.

To see how outcomes differ for labor when a technology is labor replacing, consider the arrival of the elevator. Without elevators, there would be no skyscrapers and no elevator operators. When the first elevators arrived, more elevators meant more jobs for people with a good sense of timing, capable of stopping the elevator when it was aligned with the floor. Things changed when a replacing technology emerged: the automatic elevator, which got rid of the human operator. All of the sudden, the job of elevator operator disappeared, even though we now use elevators more than ever. The demand for elevators has evidently not become saturated, just as we still demand many manufactured goods. But in a world where the jobs of machine operators have been taken over by robots, having more automobiles leave the factories does not inevitably mean more jobs for machine operators. Thus, it stands to reason that the effects of replacing technologies on jobs and wages will be very different from those of enabling technologies. Yet until recently, economists did not make such distinctions. Since the pioneering work of Jan Tinbergen—the first winner of the Nobel Prize in Economics—economists have tended to conceptualize technological progress in a purely augmenting way. According to the augmenting view of progress, new technologies will help some workers more than others but will never replace labor, meaning that workers cannot see their wages fall as technology progresses. This was a reasonable approximation of economic reality for much of the twentieth century. Indeed, most economic theory reflects the patterns of the particular times economists observe around them. The work of Tinbergen, which was published in 1974, before the age of computerization, was no exception. For much of the twentieth century, wages rose at all levels. What makes economic analysis hard is that there are few models that apply to every time and place.

The fact that wages have been falling for large groups in the American labor market for more than three decades has prompted economists to

think differently about technological change. Pathbreaking work by the economists Daron Acemoglu and Pascual Restrepo provides a helpful formal model for understanding periods of falling wages, as well as times when wages are growing for everyone, by conceptualizing technological progress as either enabling or labor replacing. This book looks at the historical record through the lens of their theoretical framework.[35] The notion of machines being capable of taking over human work is important, because it means that technology can reduce wages and employment unless it is counterbalanced by other economic forces. Even though growing productivity still raises total income—offsetting the displacement effect in part, as more spending in the economy creates other jobs elsewhere—it does not fully counterbalance the negative effects of technological displacement. In Acemoglu and Restrepo's framework, the creation of new tasks is essential to raise the demand for labor, workers' wages, and the share of national income going to labor rather than owners of capital. How workers fare, in other words, in large part depends on the race between task replacement and new task creation, and how easily workers can transition into emerging jobs.

Historically, as we shall see, the extent to which technology is labor replacing or enabling has varied greatly, leading to very different outcomes for average people. When new technologies replace workers in existing tasks, those workers' skills become obsolete. Even when technologies are replacing for some but augmenting for others, workers might suffer hardships. In recent years, the creation of new jobs for robotics engineers has provided little relief to those who lost their jobs to industrial robots on the assembly lines. The arrival of the power loom, in similar fashion, replaced the jobs of hand-loom weavers, while creating new jobs for power-loom weavers. But while hand-loom weavers' incomes diminished almost immediately, it took decades for the wages of power-loom weavers to rise, as they had to acquire new skills and a new labor market had to develop for those skills.[36] Because replacing technological progress often comes with what Schumpeter called a "perennial gale of creative destruction," there are always winners and losers.[37] The overwhelming focus of popular commentary on unanswerable questions like whether there will be enough jobs in 2050 is unfortunate.

In fact, it misses the point. Even if new jobs emerge as old ones are lost to automation, that might be little reassurance for the person who loses his or her job. Modernist writers didn't fail to take note of the automation dilemma. In *Ulysses*, for example, James Joyce's hero Leopold Bloom points out that "a pointsman's back straightened itself upright suddenly against a tramway standard by Mr. Bloom's window. Couldn't they invent something automatic so that the wheel itself much handier? Well but that fellow would lose his job then? Well but then another fellow would get a job making the new invention?"[38]

A new job was created for someone to make the new invention. But the someone was "another fellow": making the invention required a different breed of worker. Both the Industrial Revolution and the computer revolution primarily created jobs for another fellow, whose skills could not have been more different from those of the displaced worker. The first episode of industrialization is best described by the wit of the economic historian Gavin Wright, who reckoned that "in the limit we could devise an economy in which technology is designed by geniuses and operated by idiots."[39] Early factory machines, it is true, were simple enough to be operated by young boys. And as a result, middle-income artisan craftsmen were replaced by children working for a fraction of their wages in the factories. The difference this time around is obviously that children are no longer needed to operate the machines. Computer-controlled machines can run on their own. Yet computerization has also given rise to new tasks, requiring an entirely different set of skills like those of audiovisual specialists, software engineers, database administrators, and so on. Thus, we seem to have devised an economy designed by geniuses to be operated by other geniuses. Some jobs have become automated, but computers have also led to greater demand for workers with highly developed cognitive skills. Indeed, a common misconception is that automation is an extension of mechanization. Automation has replaced precisely the semiskilled machine-tending jobs that mechanization created, which once supported a large and stable middle class. Broadly speaking, those fortunate enough to have gone to college have thrived in the age of computers. But as middle-income jobs have dried up, many semiskilled workers have struggled to find decent job. During

the Industrial Revolution as well as the more recent revolution in computing, middle-aged men in middle-income jobs were the victims of progress, because their skills were unsuitable for the new jobs that emerged.

When technological change is labor replacing, how workers fare depends on their other job options. In Henrik Ibsen's play *The Pillars of Society*, written in 1877, parallels are drawn between the economic consequences of the Industrial Revolution and those of Johannes Gutenberg's printing press. One of the characters, Konsul Bernick, assumes that the fates of artisan craftsmen in the nineteenth century were similar to those of copyists when the printing press arrived, suggesting that "when printing was discovered, many copyists had to starve." The shipyard foreman Aune bluntly replies, "Would you have admired the art so much, Consul, if you had been a copyist?"[40] Though Ibsen's question was meant as a rhetorical one, copyists rarely opposed printing technology. As we shall see in chapter 1, unlike weavers—who suffered hardships from the mechanization of industry—copyists and scribes were more likely to benefit from Gutenberg's invention. Many of them did not make a living producing manuscripts. To them, the movable printing press didn't mean any loss of income. And those who copied books for a living either specialized in shorter texts that were uneconomical to produce with printing technology or became binders and designers of books. Thus, while weavers and other craftsmen, who faced worsening job options, smashed textile machines all over Europe in the eighteenth and nineteenth centuries, copyists rarely resisted the printing press in the late 1400s. Of course, the art of printing was not adopted with the same enthusiasm everywhere. Fearing that a literate population would undermine his leadership, Sultan Bayezid II issued an edict banning printing in Arabic in the Ottoman Empire in 1485, with dismal long-lasting consequences for literacy and economic growth in the region.[41] But in the light of the hostility to replacing technologies that was so widespread in Europe before the twentieth century, episodes of labor unrest accompanying the adoption of the printing press were few.

The case of the printing press illustrates a broader point: when people have good alternative job options, they are less likely to rebel against machines. Job displacement is never painless, but if people have reason

to believe that they will eventually come out ahead, they are more likely to accept the endless churn in the labor market. As we shall see, the explosive growth of middle-class jobs in the mass-production industries of the twentieth century was one key reason mechanization was allowed to progress uninterrupted: an abundance of manufacturing jobs was the best unemployment insurance people could get. In this period, a wave of enabling technologies and soaring productivity growth allowed working-class people to climb the economic ladder. Automobiles and electricity spawned new gigantic industries, and with more capital tied up in machinery, firms began to raise wages to keep workers from leaving for better jobs elsewhere. People at the top and the bottom of the income distribution saw their standard of living improve enormously, and, consequently, middle-class people accepted the reshufflings in the labor market with the expectation that they would benefit too.

Another reason people may not oppose technologies that threaten their jobs is obviously that almost everyone will benefit in their capacity as consumers. Even those who worked on Ford's and General Motors's assembly lines have to some extent benefited from the cheapening of automobiles as robots have taken their jobs. Yet machines only cheapen goods and services after they have been introduced, so that if a technology is labor replacing, consumer benefits will arise only after displacement has already occurred. More important, the individual costs from displacement, in terms of distress and lost income, will be much greater than any consumer benefits unless those workers have decent outside job options. The cheapening of textiles, for example, did not provide sufficient relief to the Luddites, who rioted against the introduction of machinery despite the consumer benefits brought by mechanization. The point is surely not that replacing technologies will be bad for people over the long run. The very opposite is true. But that alone does not provide much relief for those who see their jobs disappear, unless they can expect to find new work of equal pay.

Most economists will acknowledge that technological progress can cause some adjustment problems in the short run. What is rarely noted is that the short run can be a lifetime. And ultimately, the long run depends on policy choices made in the short run. The mere existence of

better machines is not sufficient for long run growth. As Daron Acemoglu and the political scientist James Robinson point out in *Why Nations Fail*, economic and technological development will move forward only "if not blocked by the economic losers who anticipate that their economic privileges will be lost and by the political losers who fear that their political power will be eroded."[42] Workers alone might struggle to block new technologies effectively. But the ruling elites slowed labor-replacing progress for millennia.[43] Political incumbents, for the most part, had little interest in the destabilizing process of creative destruction, as groups of economic losers could challenge the political status quo. As the eminent economic historian Joel Mokyr has argued in separate accounts:

> Any change in technology leads almost inevitably to an improvement in the welfare of some and a deterioration in that of others. To be sure, it is possible to think of changes in production technology that are Pareto superior, but in practice such occurrences are extremely rare. Unless all individuals accept the verdict of the market outcome, the decision whether to adopt an innovation is likely to be resisted by losers through non-market mechanism and political activism.[44]
>
> Britain's edge during the Industrial Revolution did not lie in the absence of resistance against technological change, but in its government's consistently and vigorously siding with the "party" for innovation. . . . Resistance to technological progress in France appears to have been more successful than in Britain, and perhaps this difference offers another explanation why Britain's Industrial Revolution was first.[45]

As I will argue in a similar vein, the early decision of British governments to consistently squash any resistance to mechanization helps explain why Britain was the first to industrialize. This decision, as we shall see, was much the result of a shift in political power. As the discovery of the New World gave rise to international trade and commerce, the power of landed wealth was challenged by a new class of "chimney aristocrats," who stood to gain from mechanization.[46] And more broadly, cascading competition among nation-states made it harder to align technological conservatism with the political status quo. The outside threat of political replacement became greater than the threat of rebelling workmen from

below. Even when workers managed to solve the so-called collective action problem and take to the streets in protest, their case was hopeless. They did not stand a chance against the British army. Many Luddites ended up being imprisoned and then sent to Australia.

The Reform Acts of 1832 and 1867 were surely important events, but they did not turn Britain into a liberal democracy. Property rights were regarded as most important, and civil rights and political rights were still lagging behind. Few people had access to education, and property ownership remained a requirement for voting—meaning that most ordinary people were politically disenfranchised. Had Britain been a liberal democracy, the case of the Luddites would surely have been much less hopeless. As Wassily Leontief, winner of the Nobel Prize in Economics, once joked, "If horses could have joined the Democratic party and voted, what happened on farms might have been different."[47] Horses might have used their political rights to bring the spread of the tractor to a halt. In similar fashion, if the Luddites had had their way, the Industrial Revolution would not have happened in Britain. Of course, there is no way of knowing exactly what would have happened; all we know is that many citizens tried to bring progress to halt by every means they had.

## The Plan of the Book

In the age of AI, as we shall see, technological progress has become increasingly labor replacing. Thus, to understand the future of progress, we must understand its political economy. The notion that technology can leave groups in the labor market worse off for the rest of their working lives is quite sufficient to justify their resistance to automation. And for governments seeking to avoid social unrest, it is also quite sufficient to justify restricting some technologies. For these reasons, the long run cannot be disconnected from the short run. Our long-run trajectories can be interrupted and changed by short run events, with dismal consequences for our long-term prosperity.

We all know that human history has proceeded very differently in different parts of the world. Economists and economic historians have devoted considerable attention to the question of why some places have

grown rich while others have remained poor. This book is not quite as ambitious. It examines why people have fared differently in the places of the world where the frontiers of technology have been allowed to progress throughout the centuries. The relationship between new technology and the wealth of humans has never been tidy and linear. History never quite repeats itself. But sometimes it surely rhymes. As I write, middle-income jobs are disappearing, and real wages are stagnating, just like in the classic period of industrialization. Of course, the computer technologies of the twenty-first century could not be more different from the machines that made modern industry. But many of their economic and social effects now look exceedingly similar. The Industrial Revolution has made us infinitely wealthier and better off over the long run. AI, similarly, has the potential to make us much wealthier, but just as in the Industrial Revolution, there is concern that it is leaving large swaths of citizens behind, possibly causing a backlash against technology itself. Many observers of current affairs have pointed out that the recent populist renaissance cannot be explained without reference to the losers of globalization. But technology has been just as important in driving down the wages of the middle class. And we have seen nothing yet. As AI becomes more pervasive, so will automation and its effects.

Economic historians have long debated why the technology boom of the 1760s in Britain took so long to produce higher standards of living, and economists are now engaged in a strikingly similar debate about why staggering advances in automation so far have failed to show results in the pockets of average people. This book is an attempt to connect two large bodies of scholarly research to put the Gates paradox in historical perspective. It tracks the expanding frontiers of technology from the invention of agriculture to the rise of AI, tracing the fates of humans as technology has progressed. I should warn the reader that this is not a balanced account. A book of this scope must be selective and carefully prioritize what it discusses. The history of technology is the subject of an extensive literature that I cannot do justice to here. Rather, by reviewing some of the most important technological advances, I shall try to convince the reader that the price of progress paid by the

workforce has varied greatly in history, depending on the nature of technological change, and has increased in the twenty-first century—which explains many of the discontents people now face.

The reader should also be aware that because the Industrial Revolution happened in Britain and technological leadership has remained firmly in Western hands since then (though it remains to be seen for how long that will be the case), this book is a Western-biased account. The West caught up with more advanced Islamic and Oriental civilizations only in the fifteenth century. But to paint the contrast of the West before and after the Industrial Revolution, I shall primarily focus on the Western experience. I should also say that most of the history in this book concerns Britain and later America. The simple reason is that the Industrial Revolution first happened in Britain. America took over world technological leadership during the so-called Second Industrial Revolution, and I shall primarily focus on the U.S. experience thereafter. As the economic historian Alexander Gershenkron noted, catch-up growth, which rests on adopting existing technologies invented elsewhere, is fundamentally different from growth that rests on expanding the frontiers of technology into the unknown, and this book focuses on the latter. Some readers may also find it disappointing that many major technological breakthroughs are not even mentioned. To take just one example, the rise of modern medicine has arguably been the greatest boon to humanity but is shamelessly left out here. Technological developments in recent years, including advances in AI, mobile robotics, machine vision, 3-D printing, and the Internet of things, are all labor saving. The purpose of this book is to shed light on present times and challenges facing the workforce today, and for this reason labor-saving technology will receive the bulk of the attention.

It must also be emphasized that though the focus in the later chapters is much on the American experience, technology is not a soloist but part of an ensemble. It interacts with institutions and other forces in society and the economy, which explains why the rise of economic inequality has been less dramatic in other industrial nations over the past three decades. Yet stagnant wages, disappearing middle-income jobs, and a falling labor share of income are common features of Western

countries, and they are all related to trends in technology. While there can be no doubt that numerous forces have shaped the income distribution, my focus here is on the long run rather than cyclical matters, and it is about the 99 percent rather than the top 1 percent. And over the grand sweep of history, average people's incomes have come to depend on technology more than any other factor.

The main challenge this book faces, however, is probably to convince the reader that we can learn from the past. Economists and economic historians alike tend to treat this idea with skepticism. As one anonymous reviewer of this manuscript put it:

> Economists are the obvious "History deniers." They are reluctant to accept that economists could learn anything from the past even as analysed by economic historians. The humbling experience of failing to predict (indeed perhaps unwittingly helping to create) the 2008 financial crisis produced an uncharacteristic expression of interest in economic history as economists sought insight into events that otherwise seemed unpredictable and disturbing. But the interest (and the humility) was temporary and superficial. However, economic historians too are reluctant to claim present-day insight from their studies of the past; it claims too much for their humble discipline. So, both of the disciplines that Frey addresses will be uneasy with his central proposition. Behind this issue is the bigger one of the communication difficulties between these two disciplines. Both have similar technical toolboxes but economics has honed its contents to a fine edge and is hostile to other approaches whereas history's contents are sometimes not on the technological frontier and have to be used in the context of a narrative. Any author wanting to make the point that we can learn from history to these two different audiences faces serious challenges.

In the remainder of this book I shall nonetheless try to convince the reader that history is more than one damn fact after another. There are broad patterns that we can learn from. When technological progress is labor replacing, history tells us, hostility and social upheaval is more likely to follow. When progress is of the enabling sort, in contrast, and

the gains from growth are more widely shared, there tends to be greater acceptance of new technologies. The chapters that follow divide economic history into four episodes. Part 1, titled "The Great Stagnation," consists of three chapters that concern preindustrial technologies and their effects on people's standard of living. Chapter 1 gives a succinct summary of advances in technology from the invention of agriculture some 10,000 years ago up until the dawn of the Industrial Revolution. It shows that many significant technologies emerged before the eighteenth century, but they failed to improve material conditions for ordinary people. Chapter 2 demonstrates that though living standards had improved before the Industrial Revolution, growth was predominantly based on trade. The Schumpeterian growth of our modern age, based on labor-saving technology, creative destruction in employment, and the acquisition of new skills, was not the engine of economic progress. Chapter 3 seeks to explain why this was the case. As we shall see, innovation also flourished at times before the Industrial Revolution, but it rarely served to replace workers—and when it did, it was vehemently opposed or even blocked. A powerful explanation for why the technologies of the Industrial Revolution did not arrive earlier is the widespread opposition to machines that threatened citizens' livelihoods. The landed classes, whose members controlled the levers of political power, had little to gain and much to lose from replacing technologies, as workers might rebel against the government in fear of losing their jobs.

The second part, called "The Great Divergence," provides a whirlwind tour of the Industrial Revolution in Britain. It shows that preindustrial monarchs were right to fear the disruptive force of machinery. As the mechanized factory displaced the domestic system, working people raged against the machine. Chapter 4 zooms in on the technologies that made the Industrial Revolution, showing that nearly all of them served to replace workers. Chapter 5 shows that the result was the hollowing out of middle-income artisan jobs, causing a great divergence within Britain—which explains why industrialization brought so much conflict. But the ruling classes now had more to gain from allowing mechanization to progress, and effectively enforced the first machine age on

the populace. Workers' resistance ended only when people began to see their wages rise in the closing decades of the Industrial Revolution.

Part 3, titled "The Great Leveling," shifts the focus to the American experience. With the Second Industrial Revolution, America took over technological leadership from Britain and the world. The purpose of this part is to examine why the twentieth century did not see the same hostility to mechanization, even as the frontiers of technology were advanced at an accelerating pace. Chapter 6 sketches the technological changes that accompanied the Second Industrial Revolution. It examines the enormous shifts that took place in the labor market as factories electrified, households mechanized, and people left the countryside for mass production industries in the city. We all know that these transitions weren't painless. Chapter 7 shows how machinery anxiety returned temporarily, as parts of the workforce struggled to adjust as some occupations vanished. But even though concerns about new technologies taking people's jobs were widespread at times, few people seriously believed that restricting the use of machines was a good idea. Why? America perhaps had the most violent labor history of the industrial world, but after the 1870s, workers rarely, if ever, targeted machines when violence erupted. Chapter 8 is devoted to the question of why labor didn't oppose machines in the way it did in the nineteenth century. I harbor no illusions that I have succeeded in providing a full answer to that question, but technology is certainly part of the story. A flow of enabling technologies pulled people into new and better-paying jobs in the smokestack cities of the Second Industrial Revolution. As labor began to see technology as working in its self-interest, the rational response became to seek to minimize the adjustment costs imposed on the workforce rather than retarding technological progress. Labor de facto accepted a laissez-faire regime with regard to mechanization but insisted on establishing a welfare and educational system to help people adjust while making individual costs for those who lost their jobs more narrowly constrained. This became the social contract of the twentieth century.

Part 4, called "The Great Reversal," concerns the era of computers. Chapter 9 shows that the age of automation was not a continuation of

twentieth-century mechanization. On the contrary, it was a complete reversal of it. The first three-quarters of the twentieth century has rightly been regarded as producing "the greatest levelling of all time."[48] It was a period of egalitarian capitalism when workers' wages rose at all ranks, to the point where Karl Marx's proletariat could join the middle class. In the 1970s, the American middle class had become a diverse blend of blue- and white-collar citizens. Many of these workers tended machines of some kind, in offices and factories. As we shall see, robots and other computer-controlled machines cut out precisely the middle-income factory and office jobs that mechanization created. Chapter 10 shifts the focus from the aggregate to the communities that have seen jobs disappear. Despite the promise of digital technology to flatten the world, it has done the opposite. Since the dawn of the computer revolution, new jobs have overwhelmingly been clustered in cities with skilled populations, while automation has replaced jobs in old manufacturing powerhouses, amplifying the polarization of the American social fabric along geographic lines. And as America has become increasingly polarized along economic lines, it has also become more politically polarized.

Chapter 11 turns to the question of why citizens who have seen their wages fall have not demanded more compensation, as the median voter theorem would predict. If the middle class declines and inequality rises, we would expect workers to vote for more redistributive policies. One reason that they haven't, I shall argue, is that they have lost political influence. Growing socioeconomic segregation has made people who have suffered hardships increasingly detached from the rest of American society. Meanwhile, the would-be working class, whose members would have flocked into the factories during the postwar boom years, has become increasingly detached from both labor unions and mainstream political parties. The growing populist appeal, it seems, in large part reflects diminishing opportunities for the losers to globalization and automation and the lack of a political response to address their concerns. Globalization has already become a populist target. Looking forward, however, more and more workers are becoming shielded from the force of globalization, as a growing percentage of the workforce is employed in nontradable sectors of the economy. But they are not shielded


FIGURE 2: Number of Laundresses in Private Households in the U.S., 1850–1990
*Source: M. Sobek, 2006, "Detailed Occupations—All Persons: 1850–1990 [Part 2]. Table Ba1396-1439," in* Historical Statistics of the United States, Earliest Times to the Present: Millennial Edition, *ed. S. B. Carter et al. (New York: Cambridge University Press).*

from automation. If current economic trends persist for several years more or even decades, as they did during the Industrial Revolution, there is nothing that shields automation from becoming a target, as globalization already has.

Part 5 is titled "The Future," although it does not attempt to predict what will happen. As discussed above, much depends on the race between replacing and enabling technologies, but obviously the next three decades must not mirror the past three. The idea here is not that we can simply extrapolate from current trends, which is what economists usually do. Nor is my ambition to predict future technological breakthroughs. The best I can do is examine the prototypical technologies coming out of the labs today that have not yet found widespread use. Take, for example, the employment prospects of laundresses, which peaked around 1910—the year when Alva J. Fisher took out a patent for the first electric washing machine, called Thor (figure 2). If economists

had extrapolated from the recent past in 1910, they would have inferred that there would be jobs in abundance for people doing laundry in the coming decades. By looking to trends in technology, in contrast (which is what chapter 12 will do), one might have concluded that the electric washing machine would replace laundresses in this task.

After reviewing many recent technological developments, including in machine learning, machine vision, sensors, various subfields of AI, and mobile robotics, my conclusion is that while these technologies will spawn new tasks for labor, they are predominantly replacing technologies and will continue to worsen the employment prospects for the already shattered middle class. Thus, assuming that the positive attitudes toward technological progress of the twentieth century will continue to hold, regardless of how working people fare from automation, is an exceedingly strong assumption. As we shall see, people are already turning more pessimistic about the future and even about automation. A majority of Americans would vote for policies to restrict it, and populists may well tap in to growing automation anxiety. How events play out will likely depend on policy choices. To that end, chapter 13 concludes by sketching some strategies and pathways to help people adjust.

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