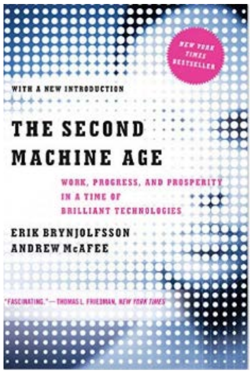


The Second Machine Age: Work, Progress, and Prosperity in a Time of Brilliant Technologies, 2016

by Erik Brynjolfsson and Andrew McAfee

https://www.amazon.com/Second-Machine-Age-Prosperity-Technologies/dp/0393350649

You can see the authors discussing robots and their effect on the economy here:

https://vimeo.com/econexcel/robots

pw is HistEcon

CHAPTER 9

THE SPREAD

"An imbalance between rich and poor is the oldest and most fatal ailment of all republics."

—Plutarch

OF THE 3.5 TRILLION photos that have been snapped since the first image of a busy Parisian street in 1838, fully 10 percent were taken in the last year.[1] Until recently, most photos were analog, created using silver halide and other chemicals. But analog photography peaked in 2000.[2] Today, over 2.5 billion people have digital cameras and the vast majority of photos are digital.[3] The effects are astonishing: it has been estimated that more photos are now taken every two minutes than in all of the nineteenth century.[4] We now record the people and events of our lives with unprecedented detail and frequency, and share them more widely and easily than ever before.

While digitization has obviously increased the quantity and convenience of photography, it has also profoundly changed the economics of photography production and distribution. A team of just fifteen people at Instagram created a simple app that over 130 million customers use to share some sixteen billion photos (and counting).[5] Within fifteen months of its founding, the company was sold for over $1 billion to Facebook. In turn, Facebook itself reached one billion users in 2012. It had about 4,600 employees[6] including barely 1,000 engineers.[7]

1. Jonathan Good, "How Many Photos Have Ever Been Taken?," *1000memories*, September 15, 2011, http://blog.1000memories.com/94-number-of-photos-ever-taken-digital-and-analog-in-shoebox (accessed August 10, 2013).

2. Ibid.

3. Tomi Ahonen, "Celebrating 30 Years of Mobile Phones, Thank You NTT of Japan," *Communities Dominate Brands*, November 13, 2009, http://communities-dominate.blogs.com/brands/2009/11/celebrating-30-years-of-mobile-phones-thank-you-ntt-of-japan.html (accessed September 11, 2013).

4. Good, "How Many Photos Have Ever Been Taken?"

5. Craig Smith, "By the Numbers: 12 Interesting Instagram Stats," *Digital Marketing Ramblings . . .*, June 23, 2013, http://expandedramblings.com/index.php/important-instagram-stats/ (accessed August 10, 2013).

6. Leena Rao, "Facebook Will Grow Headcount Quickly In 2013 To Develop Money-Making Products, Total Expenses Will Jump By 50 Percent," *TechCrunch*, January 30, 2013, http://techcrunch.com/2013/01/30/zuck-facebook-will-grow-headcount-quickly-in-2013-to-develop-future-money-making-products/ (accessed August 10, 2013).

7. Brad Stone and Ashlee Vance, "Facebook's 'Next Billion': A Q&A With Mark Zuckerberg," *Bloomberg Businessweek*, October 4, 2012, http://www.businessweek.com/articles/2012-10-04/facebooks-next-billion-a-q-and-a-with-mark-zuckerberg (accessed September 11, 2013).

Contrast these figures with pre-digital behemoth Kodak, which also helped customers share billions of photos. Kodak employed 145,300 people at one point, one-third of them in Rochester, New York, while indirectly employing thousands more via the extensive supply chain and retail distribution channels required by companies in the first machine age. Kodak made its founder, George Eastman, a rich man, but it also provided middle-class jobs for generations of people and created a substantial share of the wealth created in the city of Rochester after company's founding in 1880. But 132 years later, a few months before Instagram was sold to Facebook, Kodak filed for bankruptcy.[8] Photography has never been more popular. Today, seventy billion photos are uploaded to Facebook each year, and many times more are shared via other digital services like Flickr at nearly zero cost. These photos are all digital, so hundreds of thousands of people who used to work making photography chemicals and paper are no longer needed. In a digital age, they need to find some other way to support themselves.

The evolution of photography illustrates *the bounty* of the second machine age, the first great economic consequence of the exponential, digital, combinatorial progress taking place at present. The second one, *spread*, means there are large and growing differences among people in income, wealth, and other important circumstances of life. We've created a cornucopia of images, sharing nearly four hundred billion "Kodak moments" each year with a few clicks of a mouse or taps on a screen. But companies like Instagram and Facebook

8. "Kodak's Growth and Decline: A Timeline," *Rochester Business Journal*, January 19, 2012, http://www.rbj.net/print_article.asp?aID=190078.

employ a tiny fraction of the people that were needed at Kodak. Nonetheless, Facebook has a market value several times greater than Kodak ever did and has created at least seven billionaires so far, each of whom has a net worth ten times greater than George Eastman did. The shift from analog to digital has delivered a bounty of digital photos and other goods, but it has also contributed to an income distribution that is far more spread out than before.

Photography is not an isolated example of this shift. Similar stories have been and will be told in music and media; in finance and publishing; in retailing, distribution, services, and manufacturing. In almost every industry, technological progress will bring unprecedented bounty. More wealth will be created with less work. But at least in our current economic system, this progress will also have enormous effects on the distribution income and wealth. If the work a person produces in one hour can instead be produced by a machine for one dollar, then a profit-maximizing employer won't offer a wage for that job of more than one dollar. In a free-market system, either that worker must accept a wage of one dollar an hour or find some new way to make a living. Conversely, if a person finds a new way to leverage insights, talents, or skills across one million new customers using digital technologies, then he or she might earn one million times as much as would be possible otherwise. Both theory and data suggest that this combination of bounty and spread is not a coincidence. Advances in technology, especially digital technologies, are driving an unprecedented reallocation of wealth and income. Digital technologies can replicate valuable ideas, insights, and innovations at very low cost. This creates bounty for society and wealth for innovators, but diminishes the demand for previously important types of labor, which can leave many people with reduced incomes.

The combination of bounty and spread challenges two common though contradictory worldviews. One common view is that advances in technology always boost incomes. The other is that automation hurts workers' wages as people are replaced by machines. Both of these have a kernel of truth, but the reality is more subtle. Rapid advances in our digital tools are creating unprecedented wealth, but there is no economic law that says all workers, or even a majority of workers, will benefit from these advances.

For almost two hundred years, wages did increase alongside productivity. This created a sense of inevitability that technology helped (almost) everyone. But more recently, median wages have stopped tracking productivity, underscoring the fact that such a decoupling is not only a theoretical possibility but also an empirical fact in our current economy.

This is false. The authors do not know, like you and I do, about Engel's Pause.

How's the Median Worker Doing?

Let's review some basic facts.

A good place to start is median income—the income of the person at the fiftieth percentile of the total distribution. The year 1999 was the peak year for the real (inflation-adjusted) income of the median American household. It reached $54,932 that year, but then started falling. By 2011, it had fallen nearly 10 percent to $50,054, even as overall GDP hit a record high. In particular, wages of unskilled workers in the United States and other advanced countries have trended downward.

Meanwhile, for the first time since before the Great Depression, over half the total income in the United States went to the top 10 percent of Americans in 2012. The top 1 percent earned over 22 percent of income, more than doubling their share since the early 1980s. The share of income going to the top hundredth of one percent of

Americans, a few thousand people with annual incomes over $11 million, is now at 5.5 percent, after increasing more between 2011 and 2012 than any year since 1927–28.[9]

Several other metrics have also been increasingly unequal. For instance, while overall life expectancy continues to rise, life expectancies for some groups have started to fall. According to a study by S. Jay Olshansky and his colleagues published in *Health Affairs*, the average American white woman without a high school diploma had a life expectancy of 73.5 years in 2008, compared to 78.5 years in 1990. Life expectancy for white men without a high school education fell by three years during this period.[10]

It's no wonder that protests broke out across America even as it was beginning to recover from the Great Recession. The Tea Party movement on the right and the Occupy movement on the left each channeled the anger of the millions of Americans who felt the economy was not working for them. One group emphasized government mismanagement and the other abuses in the financial services sector.

How Technology Is Changing Economics

While undoubtedly both of these problems are important, the more fundamental challenge is deep and structural, and is the

9. According to an analysis of 2006 tax returns in the United States by Emmanuel Saez of University of California, Berkeley.

10. In contrast, life expectancy for men and women with more than a high school education increased during this period.

result of the diffusion to the second machine age technologies that increasingly drive the economy.

Recently we overheard a businessman speaking loudly (and cheerfully) into his mobile phone: "No way. I don't use an H&R Block tax preparer anymore. I've switched to TurboTax software. It's only forty-nine dollars, and it's much quicker and more accurate. I love it!" The businessman was better off. He had a better service at a lower price. Multiplied by millions of customers, TurboTax has created a great deal of value for its users, not all of which even shows up in the GDP statistics. The creators of TurboTax are also better off—one is a billionaire. But tens of thousands of tax preparers now find their jobs and incomes threatened.

The businessman's experience holds a mirror to the broader changes in the economy. Consumers are better off and enormous wealth is created, but a relatively small group of people often earns most of the income from the new products or services. Like the chemists who used silver halide to create camera film in the 1990s, human tax preparers have a hard time competing with machines. They can be made worse off by advances in technology, not just relative to the winners, but also relative to their income when they were working with the older technologies.

The crucial reality from the standpoint of economics is that it takes only a relatively small number of designers and engineers to create and update a program like TurboTax. As we saw in chapter 4, once the algorithms are digitized they can be replicated and delivered to millions of users at almost zero cost. As software moves to the core of every industry, this type of production process and this type of company increasingly populates the economy.

A Smaller Slice of a Bigger Pie

What happens when you scale up these types of examples to a whole economy? Is there something bigger going on? The data say yes.

Between 1983 and 2009, Americans became vastly wealthier overall as the total value of their assets increased. However, as noted by economists Ed Wolff and Sylvia Allegretto, the bottom 80 percent of the income distribution actually saw a net *decrease* in their wealth.[11] Taken as a group, the top 20 percent got not 100 percent of the increase, but more than 100 percent. Their gains included not only the trillions of dollars of wealth newly created in the economy but also some additional wealth that was shifted in their direction from the bottom 80 percent. The distribution was also highly skewed even among relatively wealthy people. The top 5 percent got 80 percent of the nation's wealth increase; the top 1 percent got over half of that, and so on for ever-finer subdivisions of the wealth distribution. In an oft-cited example, by 2010 the six heirs of Sam Walton's fortune, earned when he created Walmart, had more net wealth than the bottom 40 percent of the income distribution in America.[12] In part, this reflects the fact that thirteen million families had a negative net worth.

Along with wealth, the income distribution has also shifted. The top 1 percent increased their earnings by 278 percent between 1979 and 2007, compared to an increase of just 35 percent for those in the middle of the income distribution. The top 1 percent earned over 65 percent of

11. Sylvia Allegretto, "The State of Working America's Wealth, 2011," Briefing Paper No. 292, Economic Policy Institute, Washington, D.C.
12. See for example, Josh Bivens, "Inequality, Exhibit A: Walmart and the Wealth of American Families," *Working Economics*, Economic Policy Institute blog, http://www.epi.org/blog/inequality-exhibit-wal-mart-wealth-american/ (accessed September 17, 2013).

income in the United States between 2002 and 2007. According to Forbes, the collective net worth of the wealthiest four hundred Americans reached a record two trillion dollars in 2013, more than doubling since 2003.[13]

IN SHORT, median income has increased very little since 1979, and it has actually fallen since 1999. But that's not because growth of overall income or productivity in America has stagnated; as we saw in chapter 7, GDP and productivity have been on impressive trajectories. Instead, the trend reflects a significant reallocation of who is capturing the benefits of this growth, and who isn't.

This is perhaps easiest to see if one compares *average* income with *median* income. Normally, changes in the average income (total income divided by the total number of people) are not very different from changes in median income (income of the person exactly in the middle of the income distribution—half earn more and half earn less). However, in recent years, the trends have diverged significantly, as shown in figure 9.1.

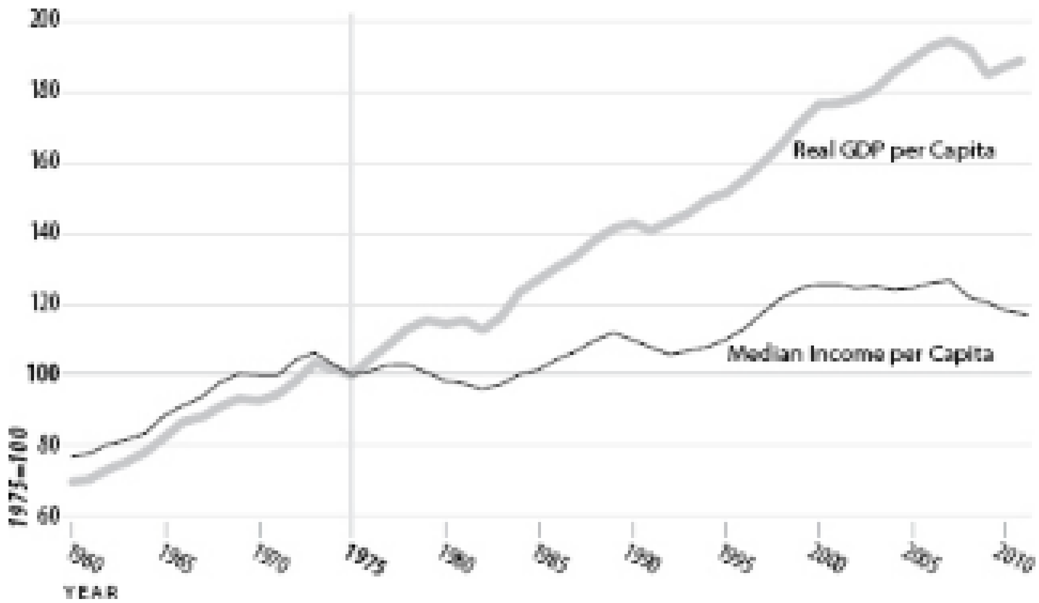
How is this possible? Consider a simple example. Ten bank tellers are drinking beers at a bar. Each of them makes $30,000 a year, so both the mean and median income of this group is $30,000. In walks the CEO and orders a beer. Now the average income of the group has skyrocketed, but the median hasn't changed at all. In general, the more skewed the incomes, the more the mean tends to diverge from the median. This is what has happened not only in our hypothetical bar but also in America as a whole.

Overall, between 1973 and 2011, the median hourly wage barely changed, growing by just 0.1 percent per year. In contrast, as discussed in chapter 7, productivity grew at an average of 1.56 percent per year during this period, accelerating a bit to 1.88 percent per year from 2000 to 2011. Most of the growth in productivity directly translated into

13. Luisa Kroll, "Inside the 2013 Forbes 400: Facts and Figures On America's Richest," *Forbes*, September 16, 2013, http://www.forbes.com/sites/luisakroll/2013/09/16/inside-the-2013-forbes-400-facts-and-figures-on-americas-richest/ (accessed September 16, 2013).

comparable growth in average income. The reason why median income growth was so much lower was primarily because of increases in inequality.[14]

FIGURE 9.1 Real GDP vs. Median Income per Capita



The Three Pairs of Winners and Losers

In the past couple of decades, we've seen changes in tax policy, greater overseas competition, ongoing government waste, and Wall Street shenanigans. But when we look at the

[14] About one-third of the difference reflected technical differences in the way output prices are calculated when used in productivity calculations versus the consumer prices used in calculating income. In addition, about 12 percent was due to the growth of nonwage benefits such as health care. See Lawrence Mishel, "The Wedges between Productivity and Median Compensation Growth," Economic Policy Institute, April 26, 2012, http://www.epi.org/publication/ib330-productivity-vs-compensation/. When looking at household income, about 20 percent of the decline reflects the fact that households are somewhat smaller than they were thirty years ago.

data and research, we conclude that none of these are the primary driver of growing inequality. Instead, the main driver is exponential, digital, and combinatorial change in the technology that undergirds our economic system. This conclusion is bolstered by the fact that similar trends are apparent in most advanced countries. For instance, in Sweden, Finland, and Germany, income inequality has actually grown more quickly over the past twenty to thirty years than in the United States.[15] Because these countries started with less inequality in their income distributions, they continued to be less unequal than the United States, but the underlying trend is similar worldwide across sometimes markedly different institutions, government policies, and cultures.

As we discussed in our earlier book *Race Against the Machine*, these structural economic changes have created three overlapping pairs of winners and losers. As a result, not everyone's share of the economic pie is growing. The first two sets of winners are those who have accumulated significant quantities of the right capital assets. These can be either nonhuman capital (such as equipment, structures, intellectual property, or financial assets), or human capital (such as training, education, experience, and skills). Like other forms of capital, human capital is an asset that can generate a stream of income. A well-trained plumber can earn more each year than an unskilled worker, even if they both work the same number of hours. The third group of winners is made up of the superstars among us who have special talents—or luck.

15. Data from the Organization for Economic Cooperation and Development (OECD) show that income inequality increased in seventeen of twenty-two nations including Mexico, the United States, Israel, United Kingdom, Italy, Australia, New Zealand, Japan, Canada, Germany, Netherlands, Luxembourg, Finland, Sweden, Czech Republic, Norway, and Denmark. See "An Overview of Growing Income Inequalities in the OECD Countries: Main Findings," from the OECD, 2011, http://www.oecd.org/social/soc/49499779.pdf.

In each group, digital technologies tend to increase the economic payoff to winners while others become less essential, and hence less well rewarded. The overall gains to the winners have been larger than total losses for everyone else. That simply reflects the fact we discussed earlier: productivity and total income have grown in the overall economy. This good news offers little consolation to those who are falling behind. In some cases the gains, however large, have been concentrated among a relatively small group of winners, leaving the majority of people worse off than before.

Skill-Biased Technical Change

The most basic model economists use to explain technology's impact treats it as a simple multiplier on everything else, increasing overall productivity evenly for everyone.[16] This model can be described in mathematical equations. It is used in most introductory economics classes and provides the foundation for the common—and until recently, very sensible—intuition that a rising tide of technical progress will lift all boats, that it will make all workers more productive and hence more valuable. With technology as a multiplier, an economy is able to produce more output each year with the same inputs, including labor. And in the basic model all labor is affected equally by technology, meaning every hour worked produces more value than it used to.

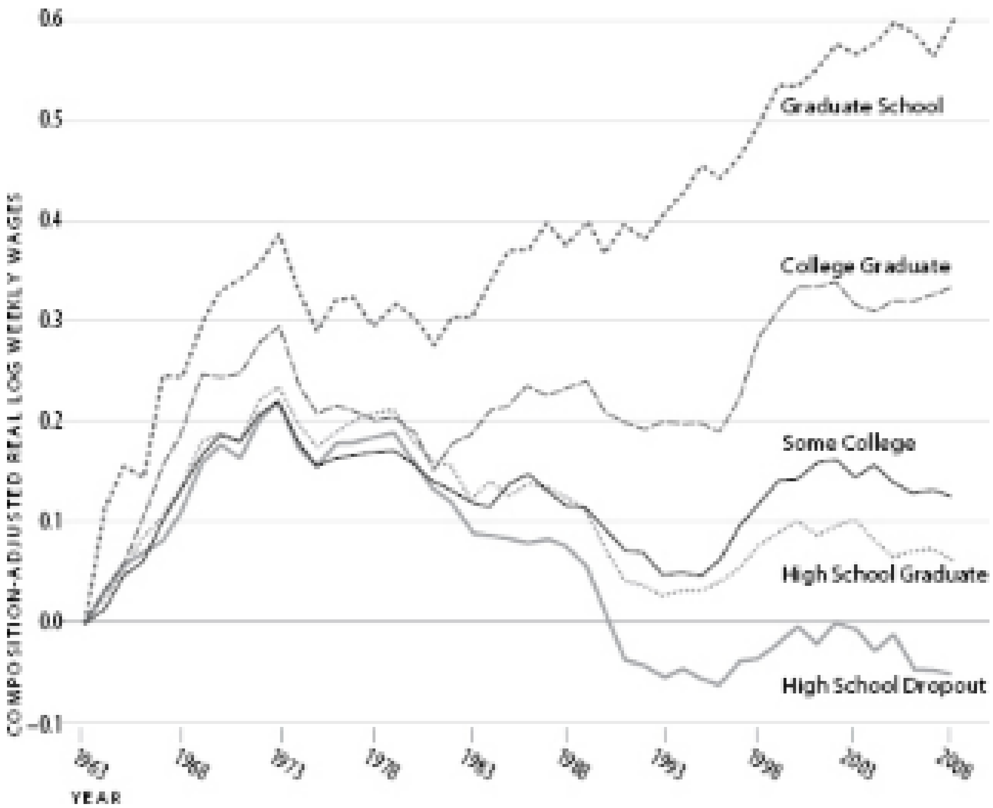
16. See, for instance, Robert M. Solow, "Technical Change and the Aggregate Production Function," *Review of Economics and Statistics* 39, no. 3 (1957): 312–20, doi:10.2307/1926047.

A slightly more complex model allows for the possibility that technology may not affect all inputs equally, but rather may be 'biased' toward some and against others. In particular, in recent years, technologies like payroll processing software, factory automation, computer-controlled machines, automated inventory control, and word processing have been deployed for routine work, *substituting* for workers in clerical tasks, on the factory floor, and doing rote information processing.

By contrast, technologies like big data and analytics, high-speed communications, and rapid prototyping have *augmented* the contributions made by more abstract and data-driven reasoning, and in turn have increased the value of people with the right engineering, creative, or design skills. The net effect has been to decrease demand for less skilled labor while increasing the demand for skilled labor. Economists including David Autor, Lawrence Katz and Alan Krueger, Frank Levy and Richard Murnane, Daron Acemoglu, and many others have documented this trend in dozens of careful studies.[17] They call it *skill-biased technical change*. By definition, skill-biased technical change favors people with more human capital.

17. See David H. Autor, Lawrence F. Katz, and Alan B. Krueger, "Computing Inequality: Have Computers Changed the Labor Market?," Working Paper (National Bureau of Economic Research, March 1997), http://www.nber.org/papers/w5956; F. Levy and R. J. Murnane, *The New Division of Labor: How Computers Are Creating the Next Job Market* (Princeton, NJ: Princeton University Press, 2012); D. Autor, "The Polarization of Job Opportunities in the U.S. Labor Market," The Brookings Institution, http://www.brookings.edu/research/papers/2010/04/jobs-autor (accessed August 10, 2013); and Daron Acemoglu and David Autor, "Skills, Tasks and Technologies: Implications for Employment and Earnings," Working Paper (National Bureau of Economic Research, June 2010), http://www.nber.org/papers/w16082.

FIGURE 9.2 Wages for Full-Time, Full-Year Male U.S. Workers, 1963–2008



This is the best graph in the book. Look at it carefully. Think about it.

The effects of skill-biased technical change can be vividly seen in figure 9.2, which is based on data from a paper by MIT economists Daron Acemoglu and David Autor.[18] The lines tell a story about the diverging paths of millions of workers over recent generations. Before 1973, American workers all enjoyed brisk wage growth. The rising tide of productivity increased everyone's incomes, regardless of their educational levels. Then came the massive oil shock and recession of the 1970s, which reversed the gains for all groups. However, after that, we began to see a growing spread of incomes. By the early 1980s, those with college degrees started to see their wages growing again. Workers

18. Daron Acemoglu and David Autor, "Skills, Tasks and Technologies: Implications for Employment and Earnings," *Handbook of Labor Economics* 4 (2011): 1043–1171.

with graduate degrees did particularly well. Meanwhile, workers without college degrees were confronted with a much less attractive labor market. Their wages stagnated or, if they were high school dropouts, actually fell. It's not a coincidence that the personal computer revolution started in the early 1980s; the PC was actually *Time* magazine's "machine of the year" in 1982.

The economics of the story become even more striking when one considers that the number of college graduates grew very rapidly during this period. The number of people enrolled in college more than doubled between 1960 and 1980, from 758,000 to 1,589,000.[19] In other words, there was a large increase in the supply of educated labor. Normally, greater supply leads to lower prices. In this case, the flood of graduates from college and graduate school should have pushed down their relative wages, but it didn't.

The combination of higher pay despite growing supply can only mean that the relative *demand* for skilled labor increased even faster than supply. And at the same time, the demand for tasks that could be completed by high school dropouts fell so rapidly that there was a glut of this type of worker, even though their ranks were thinning. The lack of demand for unskilled workers meant ever-lower wages for those who continued to compete for low-skill jobs. And because most of the people with the least education already had the lowest wages, this change increased overall income inequality.

Organizational Coinvention

While a one-for-one substitution of machines for people sometimes occurs, a broader reorganization in business culture may have been an even more important path for skill-biased change. Work that Erik did with Stanford's Tim Bresnahan, Wharton's Lorin Hitt, and MIT's Shinkyu Yang found that companies used digital technologies to reorganize decision-making authority, incentives systems, information

19. See "Digest of Education Statistics, 1999," National Center for Education Statistics, http://nces.ed.gov/programs/digest/d99/d99t187.asp (accessed August 10, 2013).

flows, hiring systems, and other aspects of their management and organizational processes.[20] This coinvention of organization and technology not only significantly increased productivity but tended to require more educated workers and reduce demand for less-skilled workers. This reorganization of production affected those who worked directly with computers as well as workers who, at first glance, seemed to be far from the technology. For instance, a designer with a knack for style might find herself in greater demand at a company with flexible equipment in distant factories that can quickly adapt to the latest fashions, while an airport ticket agent might find himself replaced by an Internet website he never knew existed, let alone worked with.

Among the industries in the study, each dollar of computer capital was often the catalyst for more than ten dollars of complementary investments in "organizational capital," or investments in training, hiring, and business process redesign.[21] The reorganization often eliminates a lot of routine work, such as repetitive order entry, leaving behind a residual set of tasks that require relatively more judgment, skills, and training.

Companies with the biggest IT investments typically made the biggest organizational changes, usually with a lag of five to seven years before seeing the full performance benefits.[22] These companies had the biggest increase in the demand for skilled work relative to unskilled work.[23] The lags reflected the time that it takes for managers and workers to figure out new

20. See T. F. Bresnahan, E. Brynjolfsson, and L. M. Hitt, "Information Technology, Workplace Organization, and the Demand for Skilled Labor: Firm-level Evidence," *Quarterly Journal of Economics*, 117, no. 1 (2002): 339–76. See also E. Brynjolfsson, L. M. Hitt, and S. Yang, "Intangible Assets: Computers and Organizational Capital," Brookings Papers on Economic Activity, 2002, pp. 137–98.

21. See Brynjolfsson, Hitt, and Yang, "Intangible Assets: Computers and Organizational Capital," and Erik Brynjolfsson, David Fitoussi, and Lorin Hitt, "The IT Iceberg: Measuring the Tangible and Intangible Computing Assets," Working Paper (October 2004).

22. E. Brynjolfsson and L. M. Hitt, "Computing Productivity: Firm-level Evidence," *Review of Economics and Statistics* 8, no. 4 (2003): 793–808.

23. Timothy F. Bresnahan, Erik Brynjolfsson, and Lorin M. Hitt, "Information Technology, Workplace Organization, and the Demand for Skilled Labor: Firm-Level Evidence," *Quarterly Journal of Economics* 117, no. 1 (2002): 339–76, doi:10.1162/003355302753399526.

ways to use the technology. As we saw in our earlier discussion of electrification and factory design, businesses rarely get significant performance gains from simply "paving the cowpaths" as opposed to rethinking how the business can be redesigned to take advantage of new technologies.[24] Creativity and organizational redesign are crucial to investments in digital technologies.[*]

This means that the best way to use new technologies is usually not to make a literal substitution of a machine for each human worker, but to restructure the process. Nonetheless, some workers (usually the less skilled ones) are still eliminated from the production process and others are augmented (usually those with more education and training), with predictable effects on the wage structure. Compared to simply automating existing tasks, this kind of organizational coinvention requires more creativity on the part of entrepreneurs, managers, and workers, and for that reason it tends to take time to implement the changes after the initial invention and introduction of new technologies. But once the changes are in place, they generate the lion's share of productivity improvements.

The Skill Set Affected by Computerization Is Evolving

If we look more closely at the jobs eliminated as companies reorganized, *skill-biased technical change* can be a bit of a misleading moniker. In particular, it would be a mistake to assume that all 'college-level tasks' are hard to automate while 'kindergarten tasks' are easy. In recent years, 'low-skill tasks'

[*] This echoes the productivity effects of electricity discussed earlier. As with digital technologies, the biggest gains did not occur until factories were redesigned, and even workers who didn't work directly with the new machines were significantly affected.

24. Reengineering consultants like to tell the story of how, in the seventeenth century, cows roamed around Boston Common and the neighboring areas. Over time, these cow paths became well-worn, and as shops and homes were constructed, people used the same paths for their carts and carriages. Eventually cobblestones were installed, and by the twentieth century most of the paths had been paved over with asphalt, with no more cows to be seen. As anyone who's tried to drive in Boston can appreciate, having traffic flow designed by cows may not be the best way to lay out a modern city.

haven't always been the ones being automated; more often it has been 'tasks that machines can do better than humans.' Of course, that's a bit of a tautology, but a useful tautology nonetheless. Repetitive work on an assembly line is easier to automate than the work of a janitor. Routine clerical work like processing payments is easier to automate than handling customers' questions. At present, machines are not very good at walking up stairs, picking up a paperclip from the floor, or reading the emotional cues of a frustrated customer.

To capture these distinctions, work by our MIT colleagues Daron Acemoglu and David Autor suggests that work can be divided into a two-by-two matrix: cognitive versus manual and routine versus nonroutine.[25] They found that the demand for work has been falling most dramatically for routine tasks, regardless of whether they are cognitive or manual. This leads to job polarization: a collapse in demand for middle-income jobs, while nonroutine cognitive jobs (such as financial analysis) and nonroutine manual jobs (like hairdressing) have held up relatively well.

Building on Acemoglu and Autor's work, economists Nir Jaimovich of Duke University and Henry Siu of the University of British Columbia found a link between job polarization and the jobless recoveries that have defined the last three recessions. For most of the nineteenth and twentieth centuries, employment usually rebounded strongly after each recession, but since the 1990s employment didn't recover briskly after recessions. Again, it's not a coincidence that as the computerization of the economy advanced, post-recession hiring patterns changed. When Jaimovich and Siu compared the 1980s, 1990s, and 2000s, they found that the demand for routine cognitive tasks such as cashiers, mail clerks, and bank tellers and routine manual tasks such as machine operators, cement masons, and dressmakers was not only falling, but falling at

25. See David Autor, "The Polarization of Job Opportunities in the U.S. Labor Market," Brookings Institution (April 2010), http://www.brookings.edu/research/papers/2010/04/jobs-autor (accessed August 10, 2013); and Daron Acemoglu and David Autor, "Skills, Tasks and Technologies: Implications for Employment and Earnings," Working Paper (National Bureau of Economic Research, June 2010), http://www.nber.org/papers/w16082.

an accelerating rate. These jobs fell by 5.6 percent between 1981 and 1991, 6.6 percent between 1991 and 2001, and 11 percent between 2001 and 2011.[26] In contrast, both nonroutine cognitive work and nonroutine manual work grew in all three decades.

CONVERSATIONS WITH senior executives help explain this pattern in the data. A few years ago, we had a very candid discussion with one CEO, and he explained that he knew for over a decade that advances in information technology had rendered many routine information-processing jobs superfluous. At the same time, when profits and revenues are on the rise, it can be hard to eliminate jobs. When the recession came, business as usual obviously was not sustainable, which made it easier to implement a round of painful streamlining and layoffs. As the recession ended and profits and demand returned, the jobs doing routine work were not restored. Like so many other companies in recent years, his organization found it could use technology to scale up without these workers.

As we saw in chapter 2, this reflects Moravac's paradox, the insight that the sensory and motor skills we use in our everyday lives require enormous computation and sophistication.[27] Over millions of years, evolution has endowed us with billions of neurons devoted to the subtleties of recognizing a friend's face, distinguishing different types of sounds, and using fine motor control. In contrast, the

26. See N. Jaimovich and H. E. Siu, "The Trend is the Cycle: Job Polarization and Jobless Recoveries (No. w18334)," National Bureau of Economic Research, 2012.

27. As Hans Moravec put it, "it is comparatively easy to make computers exhibit adult level performance on intelligence tests or playing checkers, and difficult or impossible to give them the skills of a one-year-old when it comes to perception and mobility." Hans Moravec, *Mind Children: The Future of Robot and Human Intelligence* (Cambridge, MA: Harvard University Press, 1988).

abstract reasoning that we associate with 'higher thought' like arithmetic or logic is a relatively recent skill, developed over only a few thousand years. It often requires simpler software and less computer power to mimic or even exceed human capabilities on these types of tasks.

Of course, as we've seen throughout this book, the set of tasks machines can do is not fixed. It is constantly evolving, just as our use of the word "computer" itself has evolved from referring to a job that humans do to referring to a piece of equipment.

In the early 1950s, machines were taught how to play checkers and could soon beat respectable amateurs.[28] In January 1956, Herbert Simon returned to teaching his class and told his students, "Over Christmas, Al Newell and I invented a thinking machine." Three years later, they created a computer program modestly called the "General Problem Solver," which was designed to solve, in principle, any logic problem that could be described by a set of formal rules. It worked well on simple problems like Tic-Tac-Toe or the slightly harder Tower of Hanoi puzzle, although it didn't scale up to most real-world problems because of the combinatorial explosion of possible options to consider.

Cheered by their early successes and those of other artificial intelligence pioneers like Marvin Minsky, John McCarthy and Claude Shannon, and Simon and Newell were quite optimistic about how rapidly machines would master human skills, predicting in 1958 that a digital computer would be the world chess champion by 1968.[29] In 1965, Simon went so far as to predict, "machines will be capable, within twenty years, of doing any work a man can do."[30]

28. See chapter 6 in Jonathan Schaeffer, *One Jump Ahead: Computer Perfection at Checkers* (New York: Springer, 2009), http://public.eblib.com/EBLPublic/PublicView.do?ptiID=418209.
29. Quoted in Daniel Crevier, *AI: The Tumultuous History of the Search for Artificial Intelligence* (New York: Basic Books, 1993), p. 108.
30. Jack Copeland, "A Brief History of Computing," June 2000, http://www.alantur ing.net/turing_archive/pages/Reference%20Articles/BriefHistofCom p.html.

Simon won the Nobel Prize in Economics in 1978, but he was wrong about chess, not to mention all the other tasks that humans can do. His mistake may have been more about the timing than the ultimate outcome. After Simon made his prediction, computer chess programs improved by about forty points per year on the official Elo chess rating system. On May 11, 1997, forty years after Simon's prediction, an IBM computer called Deep Blue beat the world chess champion, Gary Kasparov, after a six-game match. Today, no human can beat even a mid-tier computer chess program. In fact, software and hardware have progressed so rapidly that by 2009, chess programs running on ordinary personal computers, and even mobile phones, have achieved grandmaster levels with Elo ratings of 2,898 and have won tournaments against the top human players.[31]

Labor and Capital

Technology is not only creating winners and losers among those with differing amounts of human capital, it is also changing the way national income is divided between the owners of physical capital and labor (people like factory owners and factory workers)—the two classical inputs to production.

When Terry Gou, the founder of Foxconn, purchased thirty thousand robots to work in the company's factories in China, he was substituting capital for labor.[32] Similarly, when an automated voice-response system usurps some of the functions of human call center operators, the production process has more capital and less labor. Entrepreneurs and managers are constantly making these types of decisions, weighing the relative costs of each type of input, as well as the effects on the quality, reliability, and variety of output that can be produced.

31. The mobile phone chess game Pocket Fritz won the Copa Mercosur tournament in Buenos Aires, Argentina, in 2009. "Breakthrough Performance by Pocket Fritz 4 in Buenos Aires," *Chess News*, http://en.chessbase.com/Home/TabId/211/PostId/4005719/breakthrough-performance-by-pocket-fritz-4-in-buenos-aires.aspx (accessed August 10, 2013).

32. Steve Musil, "Foxconn Reportedly Installing Robots to Replace Workers" *CNET*, November 13, 2012, http://news.cnet.com/8301-1001_3-57549450-92/foxconn-reportedly-installing-robots-to-replace-workers/ (accessed November 13, 2012).

Rod Brooks estimates that the Baxter robot we met in chapter 2 works for the equivalent of about four dollars per hour, including all costs.[33] As we discussed at the start of this chapter, to the extent that a factory owner previously employed a human to do the same task that Baxter could do, the economic incentive would be to substitute capital (Baxter) for labor as long as the human was paid more than four dollars per hour. If output stays the same, and assuming no new hires are made in engineering, management, or sales at the company, it would increase the ratio of capital to labor input.[*]

Compensation of the remaining workers could go up or down in the wake of Baxter's arrival. If their work is a close substitute for the robots', then there will be downward pressure on human wages. That will grow even worse if Moore's Law and other advances allow future versions of Baxter to work for two dollars per hour, and then one dollar per hour, and so on, while handling an increasing variety and complexity of tasks. However, economic theory also holds open the possibility that the remaining workers would see an increase in pay. In particular, if their work complements the technology, then demand for their services will increase. In addition, as technical advances increase labor productivity, employers can afford to pay more for each worker. In some cases, this is reflected directly in higher wages and benefits. In other cases, the prices of products and services fall, so the real wage of workers increases as they are able to buy more with each dollar. As productivity improves, total amount of output per person would increase but the amount earned by human workers could either fall or rise, with the remainder going to capital owners.

Of course, almost every economy has been using technology to substitute capital for labor for decades, if not centuries. Automatic threshing machines replaced a full 30 percent of the agricultural labor force in the middle of the

33. Rod Brooks gave four dollars per hour as the approximate cost of Baxter in response to a question at the Techonomy 2012 Conference in Tucson, Arizona, on November 12, 2012, during a panel discussion with

* The effect on the economy overall would depend on how other companies reacted. Output would likely increase at companies that design and build robots and, depending on how capital-intensive they are, the net ratio of capital to labor in the overall economy could increase, decrease, or stay the same. We'll discuss these effects in more detail in chapter 12.

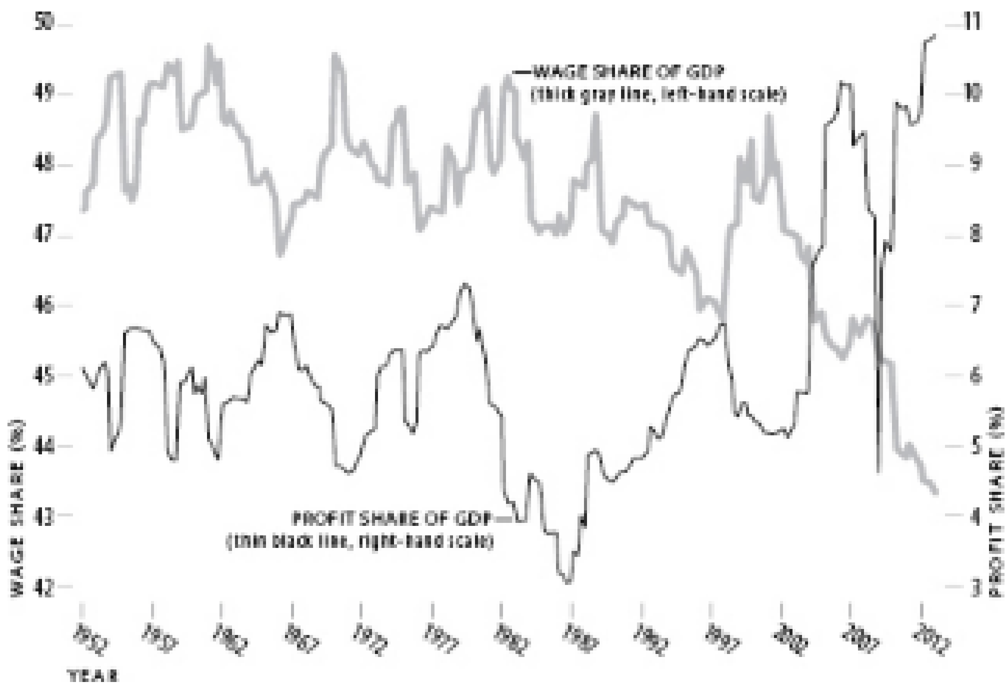
nineteenth century, and industrialization continued at a brisk pace throughout the twentieth century. Nineteenth-century economists like Karl Marx and David Ricardo predicted that the mechanization of the economy would worsen the fate of workers, ultimately driving them to a subsistence wage.[34]

What has actually happened to the relative share of capital and labor? Historically, despite changes in the technology of production, the share of overall GDP going to labor has been surprisingly stable, at least until recently. As a result, wages and living standards have grown dramatically, roughly in line with the dramatic increases in productivity. In part, this reflects the increases in human capital that have paralleled the more visible increases in equipment and buildings in the economy. Dale Jorgenson and his colleagues have estimated that the overall magnitude of the human capital in the U.S. economy, as measured by its economic value, is as much as ten times the value of the physical capital.[35] As a result, labor compensation has grown along with payments to owners of physical capital via profits, dividends, and capital gains.

Figure 9.3 shows that in the past decade, the relatively consistent division between the shares of income going to labor and physical capital seems to be coming to an end. As noted by Susan Fleck, John Glaser, and Shawn Sprague in the *Monthly Labor Review*: "Labor share averaged 64.3 percent from 1947 to 2000. In the United States, the share of GDP going to labor has declined over the past decade, falling to its lowest point in the third quarter of 2010, 57.8 percent."[36] What's more, this is a global phenomenon. Economists Loukas Karabarbounis and Brent Neiman of the University of Chicago find that "the global labor share has significantly declined since the early 1980s, with the decline occurring within the large majority of countries and industries."[37] They argue that this decline is likely due to the technologies of the information age.

34. Karl Marx, *Capital: A Critique of Political Economy* (New York: Modern Library, 1906), pp. 708–9.
35. See Dale Jorgenson, *A New Architecture for the U.S. National Accounts* (Chicago, IL: University of Chicago Press, 2006).
36. Susan Fleck, John Glaser, and Shawn Sprague, "The Compensation-Productivity Gap: A Visual Essay," *Monthly Labor Review* (January 2011), http://www.bls.gov/opub/mlr/2011/01/art3full.pdf, p. 57-69.
37. L. Karabarbounis and B. Neiman, "The Global Decline of the Labor Share (No. w19136)," National Bureau of Economic Research, 2013.

FIGURE 9.3 Wage Share of GDP vs. Corporate Profit Share of GDP



The fall in labor's share is in part the consequence of two trends we have already noted: fewer people are working, and wages for those who are working are lower than before. As a result, while labor compensation and productivity in the past rose in tandem, in recent years a growing gap has opened.

If productivity is growing and labor as a whole isn't capturing the value, who is? Owners of physical capital, to a large extent. While the economy remained mired in a slump, profits reached historic highs last year, both in absolute terms ($1.6 trillion) and as a share of GDP (26.2 percent in 2010, up from the 1960–2007 average of 20.5 percent).[38] Meanwhile, real spending on capital equipment and software has soared by 26 percent while payrolls have remained essentially flat, as noted by Kathleen Madigan.[39]

38. See http://w3.epi-data.org/temp2011/BriefingPaper324_FINAL%283%29.pdf.

39. See http://blogs.wsj.com/economics/2011/09/28/its-man-vs-machine-and-man-is-losing/.

What's more, the collapse in the share of GDP going to labor actually understates how the situation has deteriorated for the typical worker. The official measure of labor compensation includes soaring wages for a small number of superstars in media, finance, sports, and corporate positions. Furthermore, it is debatable that all of the compensation going to CEOs and other top executives is solely due to their 'labor' income. It may also reflect their bargaining power, as suggested by Harvard Law Professor Lucian Bebchuk and others.[40] In this sense, it might make sense to think of CEOs' income as due to their control of capital, not labor, at least in part.

While the share of national income to capital has been growing at the expense of labor, economic theory does not necessarily predict that this will continue, even if robots and other machines take over more and more work. The threat to capital's share comes not (just) from the bargaining power of various types of human labor, from CEOs or labor unions but, ironically, from other capital. In a free market, the biggest premiums go to the scarcest inputs needed for production. In a world where capital can be replicated at a relatively low cost (think of computer chips or even software), the marginal value of capital will tend to fall, even if more capital is used overall. The value of existing capital will actually be driven down as new capital is added cheaply at the margin. Thus, the rewards earned by capitalists may not automatically grow relative to labor. Instead the shares will depend on the exact details of the production, distribution, and governance systems.

40. See, e.g., Lucian A. Bebchuk and Yaniv Grinstein, "The Growth of Executive Pay," *Oxford Review of Economic Policy* 21 (2005): 283–303; Harvard Law and Economics Discussion Paper No. 510. Available at SSRN, http://papers.ssrn.com/abstract=648682 (accessed August 10, 2013).

Most of all, the payoff will depend on which inputs to production are scarcest. If digital technologies create cheap substitutes for labor, then it's not a good time to be a laborer. But if digital technologies also can increasingly substitute for capital, then capital owners shouldn't expect to earn high returns either. What will be the scarcest, and hence the most valuable, resource in the second machine age? This question brings us to our next set of winners and losers: superstars versus everyone else.