Part III

THE SOURCES OF FASTER AND SLOWER GROWTH

Chapter 16

THE GREAT LEAP FORWARD FROM THE 1920s TO THE 1950s: WHAT SET OF MIRACLES CREATED IT?

> I refuse to recognize that there are impossibilities. I cannot discover that anyone knows enough about anything on this earth definitely to say what is and what is not possible.
>
> —Henry Ford

INTRODUCTION

The Great Leap Forward of the American level of labor productivity that occurred in the middle decades of the twentieth century is one of the greatest achievements in all of economic history.[1] Had the economy continued to grow at the average annual growth rate that prevailed during 1870–1928, by 1950 output per hour would have been 52 percent higher than it had been in 1928. Instead the reality was a 1928–50 increase of 99 percent, a marked acceleration of the pace of economic growth compared to everything that had created growth in the six decades before 1928, including the Roaring Twenties themselves.

At first glance it may seem a surprise that so much of the progress of the twentieth century occurred between 1928 and 1950. The Great Inventions of the late nineteenth century had by 1928 already reached most urban households. Light was produced by electricity in cities and towns alike, and almost all urban housing units were connected by then not just to electricity, but also to gas, telephone, running water, and sewer lines. The motor vehicle had a more widespread effect than electricity, transforming not just urban but also rural

America. By 1926, fully 93 percent of Iowa farmers owned a motor vehicle, starting from 0 percent in 1900, and the ratio of motor vehicle registrations to the number of households in the entire country had by 1929 reached 90 percent.[2]

Part of the puzzle of the Great Leap Forward is that the data and history do not provide us with a steady unbroken record of progress between 1928 and 1950. Rather, the operation of the normal economy was obscured as the decade of the Great Depression was followed by the production miracle of World War II. The macroeconomic "lights out" is like a blackout curtain that prevents us from determining any aspect of normal macroeconomic behavior during the depression and war years. From 1929 to 1933, output, hours of work, and employment collapsed. With so many machines idle and so many buildings empty, we can learn little about the pace of technical progress or innovation during those years. And the distortions continued through the partial recovery of 1933–37, the severe recession of 1938, and then the continuous explosion of economic output from 1938 to 1945 as the economy was revived by wartime spending so enormous that in 1944, military spending amounted to 80 percent of the size of the entire economy in 1939, and real GDP in 1944 was almost double that of 1939.[3] And then, to the surprise of many economists, after the stimulus of wartime spending was removed swiftly in 1945–47, the economy did not collapse. Some mysterious elixir had converted the production achievements of the Arsenal of Democracy into a postwar cornucopia of houses, automobiles, and appliances.

Our task in this chapter is to shed light on this fundamental puzzle in American economic history: What allowed the economy of the 1950s and the 1960s so unambiguously to exceed what would have been expected on the basis of trends estimated from the six decades before 1928?[4] Our analysis in this chapter takes the word "leap" seriously. It combines substance and speculation, and asks not just about the pace of innovation, but also about what could have happened with the lights out that permanently changed the economy's capacity to produce.[5] Though this book is about long-run trends in the standard of living rather than about business cycle fluctuations, tantalizing questions are suggested by the interaction of cycles and trends. Did the Great Depression permanently retard U.S. growth? Would postwar prosperity have occurred without World War II? How were labor input, capital input, and productivity transformed between 1928 and 1950?

The chapter begins by quantifying the leap. The first step is to ask: "The leap in what?" By definition output per person is equal to labor productivity

(output per hour) times hours per person. We define the "leap" for each of these three components relative to a trend line that grows after 1928 at the same rate recorded by each concept between 1870 and 1928. We discover that by 1950, productivity growth was far above the earlier trend, whereas real GDP per person was modestly above the previous trend—and that by definition implies that hours per person were below their historic trend.

The search for explanations begins with elementary economics. An increase in real wages tends to boost productivity as firms substitute capital for labor. The New Deal passed legislation that made it much easier for labor unions to organize. In addition to pushing up real wages, labor unions also largely achieved their century-old goal of the eight-hour day. As a result, hours per person were markedly lower in the early postwar years than they had been in the 1920s.

The traditional measure of the pace of innovation and technological change is total factor productivity (TFP)—output divided by a weighted average of labor and capital input.[6] The measure of labor input allows for changes not only in the number of labor hours that are worked in a given year, but also in the average educational attainment of the labor force. Our measure of capital input is newly developed for this book and adjusts for unusual aspects of investment behavior during the 1930s and 1940s; details of these adjustments are provided in the data appendix.

The most novel aspect of this chapter is its assertion that World War II itself was perhaps the most important contributor to the Great Leap. We will examine the beneficial aspect of the war both through the demand and supply side of the economy. The war created household saving that after 1945 was spent on consumer goods that had been unavailable during the war, the classic case of "pent-up demand." A strong case can be made that World War II, however devastating in terms of deaths and casualties among the American military (albeit much less than the greater toll of deaths and wounded among other combatants), nevertheless represented an economic miracle that rescued the American economy from the secular stagnation of the late 1930s. In fact, this chapter will argue that the case is overwhelming for the "economic rescue" interpretation of World War II along every conceivable dimension, from education and the GI Bill to the deficit-financed mountain of household saving that gave a new middle class the ability to purchase the consumer durables made possible by the Second Industrial Revolution.

The supply effects are more subtle and interesting and include a vast expansion of the nation's capital stock as the government paid for new factories and equipment that were then operated by private firms to create aircraft, ships, and weapons. The expansion of government capital began during the 1930s and included not just factories to produce military goods during the war itself, but a surge of investment in infrastructure in both the 1930s and 1940s, as the nation's highway network was extended and major projects such as the Golden Gate Bridge, the Bay Bridge, the Tennessee Valley Authority (TVA), and the Boulder (later, Hoover) Dam were completed. Another supply channel boosted productivity through "learning by doing." The supply constraints of the 1942–45 war forced each firm to devise new techniques to boost output while constrained by limited capital and labor resources.

The explanation of the Great Leap then turns to the innovations of the 1920s that had not been fully exploited by 1929, as well as to the additional inventions of the 1930s and 1940s. By some measures, the 1930s were the most productive decade in terms of the numbers of inventions and patents granted relative to the size of the economy. Previous chapters of this book have pointed to technological progress during the 1930s, including in the quality and diffusion of electric appliances, improvements in the quality of automobiles, the arrival of commercial air transport, the arrival of network radio programs available in every farm and hamlet, the culmination of growth in motion picture quality and attendance, and continuing improvements in health with the invention of the first sulfa drugs. Inventions in the 1930s and 1940s also occurred in other areas not explicitly treated in previous chapters of the book, especially chemicals, plastics, and oil exploration and production.

HOW BIG WAS THE LEAP? OUTPUT, PRODUCTIVITY, AND HOURS

Throughout this book, we have equated the concept of the "standard of living" to real GDP per person while recognizing that increases in real GDP per person greatly understate the rise in the true standard of living—that is, household welfare. This understatement arises because of the inherent difficulty of measuring the value of new inventions, all of which are excluded from historical measures of real GDP. The use of official real GDP data in this section recognizes that there is an unknown degree of understatement of growth rates as a result of the unmeasured benefits of new inventions.[7]

The magnitude of the Great Leap Forward is illustrated first in figure 16–1. The straight upward-sloping line on the log scale represents the trend of growth between 1870 and 1928 in output per hour and output per person, each

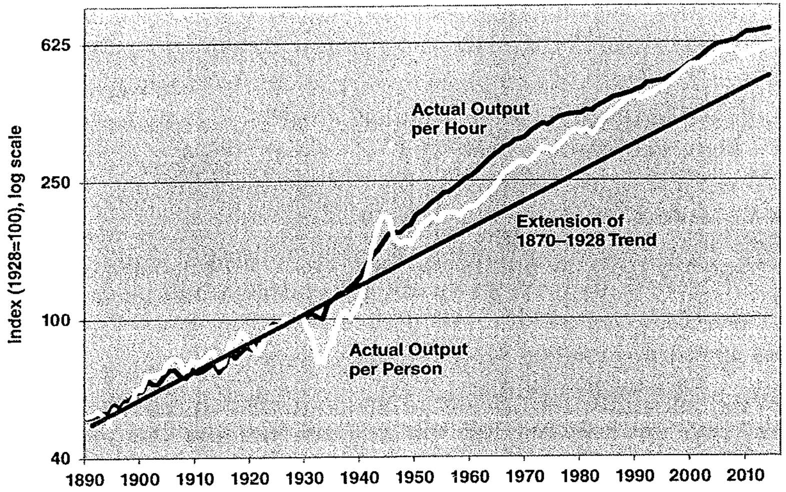

Figure 16–1. Actual Values of Output per Hour and Output per Person Compared to Extension of Their 1870–1928 Trends, 1928=100, 1890–2014
Sources: See Data Appendix for all figures in chapter 16.

growing at an annual rate of 1.9 percent per year. But actual output per hour and output per person did not behave alike after 1928. The main features of figure 16–1 pop off the page. First, deviations of actual values from the trend lines were minor before 1928. But starting with the Great Depression, the two lines diverge radically, both from trend and from each other. Output per person, as shown by the white line, collapsed during 1929–33 and soared during World War II. Then, during the postwar years, output per person was between 10 percent and 20 percent above trend (from 1947 to 1964) and then between 20 percent and 35 percent above trend (from 1965 to 2014). Output per hour (labor productivity) hardly declined at all in the Great Contraction of 1929–33 and was back to its trend by 1935. By 1941, productivity was 11 percent above trend, then reached 32 percent above trend by 1957 and 44 percent above trend in 1972. The post-1928 productivity growth miracle is perhaps the central puzzle in the American economic history of the twentieth century.

Figure 16–2 helps us better understand why the time path of output per person and of labor productivity diverged so much after 1928. It displays the percent deviation from trend of output per hour and per person and also adds an additional third line, the deviation from the historical 1870–1928 growth

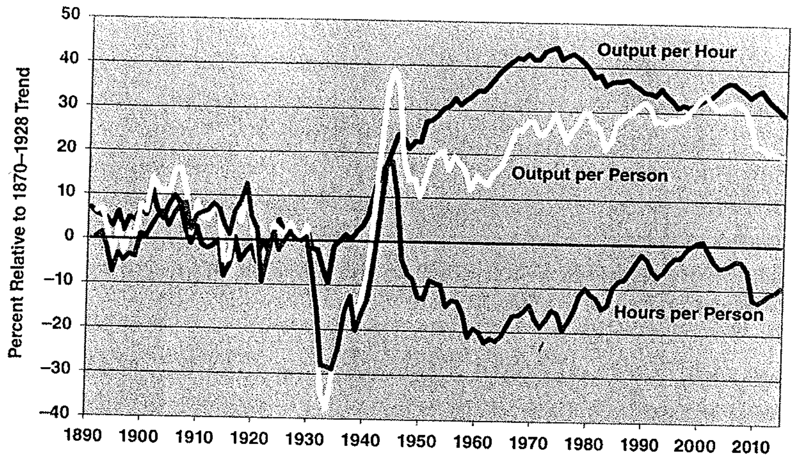

Figure 16–2. Log Ratio of Actual Values to Extension of 1870–1928 Trends of Output per Hour, Output per Person, and Hours per Person, 1890–2014

path of hours per person. Several distinctive time intervals stand out. The Great Depression of 1929–41 exhibits a parallel collapse and recovery in output per person and hours per person, implying by definition that output per hour showed little cyclical variation in the 1930s. The giant peak of all series, as achieved during World War II in 1944, reveals that the great upsurge of output per person from 1933 to 1944 was almost evenly divided between output per hour and hours per person.

The core of the puzzle addressed in this chapter occurs immediately after the war. Output per person dropped from 39 percent to 14 percent above trend between 1944 and 1950. Hours per person declined even more, from +18 to −13 percent, over the same time span. The big surprise was that labor productivity appears to have permanently increased as a result of the war. Table 16–1 shows the percent log ratios to the 1870–1928 trend for the three series for selected years. These are the base year of 1928, 1941 (the last year before World War II), 1944 (the peak year of war production), 1950, 1957, and finally the pivotal year 1972, when the ratio of labor productivity to trend reached its postwar peak.

The story told in table 16–1 identifies a set of questions to be addressed in this chapter. First, note that output per hour moved steadily higher relative to

Table 16–1. Percent Log Deviation from Extension of 1870–1928 Trend, Selected Years

	1928	1941	1944	1950	1957	1972
Output per Hour	0	11.0	20.7	27.3	32.3	44.0
Output per Person	0	6.4	38.8	14.6	16.3	26.8
Hours per Person	0	–4.6	18.1	−12.8	−15.9	−17.2
Real Wage[a]	0	13.7	19.5	26.2	38.5	56.2

Sources: Data underlying Figures 16–2 and 16–3.
Note: Trend for real wage refers to 1891–1928.

the 1870–1928 trend in each of the years shown. Why did this productivity growth surge occur? The deviations from trend of hours per person are somewhat easier to understand and include the role of labor unions in achieving the eight-hour day in the 1935–50 interval, as well as the baby boom itself in raising the population of children and thus reducing hours of work for the total population as mothers stayed home to take care of their families during the 1950s. Because the decline in hours per person relative to trend was not as large in magnitude as the rise in productivity, the postwar economy enjoyed a level of output per person substantially above the extension of the 1870–1928 trend.

WHAT CAUSED HIGHER REAL WAGES? THE ROLE OF THE NEW DEAL AND LABOR UNIONS

To explain the upsurge in labor productivity, the best place to start is with basic economic theory. In a competitive market, the marginal product of labor equals the real wage, and economists have shown that labor's marginal product under specified conditions is the share of labor in total income times output per hour.[8] If the income share of labor remains constant, then the growth rate of the real wage should be equal to that of labor's average product, the same thing as labor productivity. Could an increase in real wages have caused, directly or indirectly, the upsurge in labor productivity that occurred between the 1920s and 1950s?

Figure 16–3 copies from figure 16–2 the black line that shows the percent deviation of output per hour from its 1870–1928 trend line. Compared to this is shown the deviation from trend of the best available measure of the real inflation-adjusted wage.[9,10] In the late 1930s, the real wage began to rise more quickly than its pre-1928 trend, as did labor productivity. As shown in

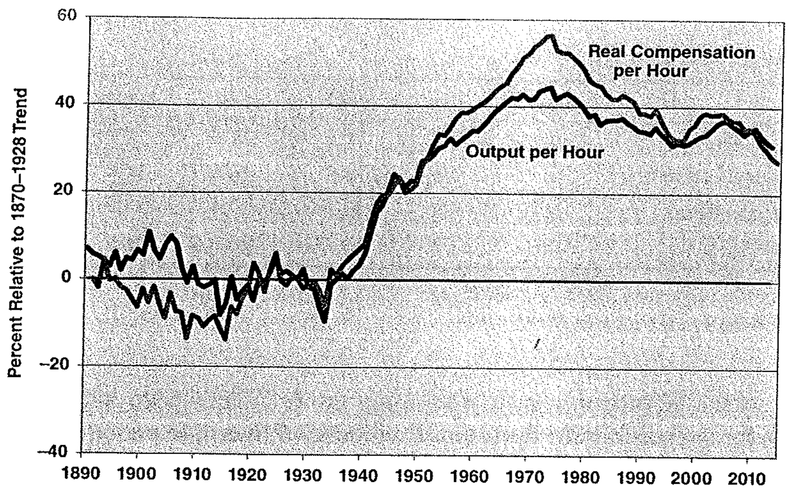

Figure 16–3. Log Ratio of Actual Values to Extension of pre-1928 Trends of Output per Hour and Real Compensation per Hour, 1890–2014

figure 16–3 and in the fourth line of table 16–1, by 1941 the real wage was already almost 14 percent above trend, somewhat higher than the 11 percent ratio to trend of labor productivity. The rise of the real wage may reflect in part the effects of New Deal Legislation, particularly the National Industrial Recovery Act of 1933–35 and the National Labor Relations Act of 1935. Because only a few industries were unionized in the late 1930s, primarily those dealing in automobiles and other durable goods, the effect of unions in boosting real wages may have spilled over to other less unionized industries. The index of the real wage relative to trend remained roughly the same as for productivity through 1950 and then between 1950 and 2007 was higher than the same ratio for productivity.[11]

The fact that both the real wage rose above its trend by more than productivity between 1950 and 1973 implies that labor's share in total income increased over this interval. The reverse occurred during 1973–2014. The growth of labor's share in the 1950s and 1960s is part of the phenomenon that Claudia Goldin and Robert Margo have called with reference to the distribution of income "The Great Compression," and the gradual shrinkage of labor's income share after the mid-1970s is consistent with rising inequality over the past three decades. We return to the inequality phenomenon in chapter 18.

The increase relative to the pre-1928 trend of both the real wage and labor productivity was in part a result of a long history of labor union agitation for higher wages and shorter hours that culminated in the 1930s. The eight-hour day was a provision of the National Labor Relations ("Wagner") Act of 1935, which set out new rules that governed the formation of unions and the conduct of free elections for labor union recruitment. Three years, later the modern system of the forty-hour week with mandatory time-and-a-half overtime for hours beyond forty was put into effect by the New Deal's Fair Labor Standards Act, passed in 1938.

The shift to the eight-hour day must have had a direct effect in boosting productivity. Edward Denison has called attention to the effect of shorter hours in reducing worker fatigue and thus improving worker efficiency. In addition, many establishments reorganized themselves to reduce business hours and conduct the same amount of business in eight hours as they formerly did in ten hours per day. However, the main upward stimulus to productivity must have come from the impetus of higher hourly wages, particularly in the late 1930s, that led firms to economize on the use of labor. This helps us to understand the explosion of productivity during World War II.

THE ROLE OF LABOR QUALITY: THE SURGE IN EDUCATIONAL ATTAINMENT

The study of the sources of productivity growth is called "growth accounting" and was pioneered by Robert Solow in the 1950s, with seminal additional contribution in the 1960s from Edward Denison, Zvi Griliches, and Dale Jorgenson.[12] This approach subdivides the growth in labor productivity into four categories:

Increases in labor quality, usually represented by changes in educational attainment
Increases in the quantity of capital relative to the quantity of labor
Increases in the quality of capital

The leftovers, alternately called "total factor productivity" or "the residual" or even "the measure of our ignorance." While often treated as a measure of innovation and technical progress, the residual incorporates every aspect not just of major innovation but of incremental tinkering and anything else that improves efficiency, including the movement from low-productivity jobs in agriculture to higher-productivity jobs in the cities.

"Labor quality" is often measured by educational attainment, and there were significant increases in the educational attainment of American youth both before and after World War II. Between 1900 and 1970, the high school graduation rates of U.S. teenagers rose from 6 percent to 80 percent, a truly monumental change that contributed to productivity growth. By 1940, half of American youth had completed high school, and a substantial fraction of the rest had experienced high school classes before dropping out. This created a more capable work force to confront the production challenges of the Arsenal of Democracy during 1941–45. Workers who had a high school education were better able to operate new and more complex machinery, both on the assembly line and in the office.

The period of most rapid increase in four-year college graduation rates was in the decade 1940–50. This was thanks in large part to the GI Bill, passed in 1944, which provided financing for every World War II veteran to attend college at the expense of the federal government. Because 16.1 million people, or 12 percent of the 1940 population, had served during the war, the effect was substantial and swamped the nation's colleges with new enrollees during 1946–49. The GI Bill also provided for support if a veteran wanted to complete a high school degree, as well as low-interest loans for home purchase and unemployment compensation for a veteran's first year out of the military.

There are other ways of expressing the improvement in educational attainment. The fraction of the U.S. workforce who had only an elementary school education declined from 75 percent in 1915 to 30 percent in 1960 to a mere 3 percent in 2005.[13] Over the same 1915–2005 interval, the fraction who had four-year college degrees, post-graduate degrees, and enrollment in college courses (without graduation) increased from 4 percent to 48 percent.

Because the rise in educational attainment proceeded at a steady pace before and after 1928, it does not contribute anything to the explanation of the main puzzle explored in this chapter: Why did labor productivity grow so much more quickly between 1928 and 1972 than it had before 1928? The increase of educational attainment, an undeniably positive creator of economic growth, cannot be counted among the factors that generated the Great Leap Forward between the 1920s and 1950s. For the missing causes, we must look elsewhere.

CAPITAL AND TFP: THE MIDCENTURY EXPLOSION OF PRODUCTIVITY

Standard production theory relates output to the quantity and quality of labor and capital. The preceding section examined the role of changes in the quality of labor made possible by higher educational attainment. Changes in the quantity and quality of capital are another possible source of the jump in labor productivity between the 1920s and 1950s. As economists in the early 1960s marveled over the richness of John Kendrick's seminal 1961 contribution to the data of growth accounting, one startling change leaped off the page. The ratio of output to capital input (the average productivity of capital) almost doubled between the 1920s and the 1950s.

The doubling is reproduced in figure 16–4, which displays the ratio of GDP to capital input from 1920 to 1972. The upper line shows the ratio of real GDP to the same concept of capital that Kendrick used, as updated from current data sources.[14] After hovering very close to 100 percent of the 1928 value during 1923–29, the ratio dropped to 78 percent during the worst years of the Great Depression, returned to 95 percent in 1935 and 144 percent in 1941, and then reached a peak of 220 percent during 1944. The big surprise came after the war, when many economists predicted that the economy would sink back into the dire conditions of the 1930s. The output-capital ratio dropped only to

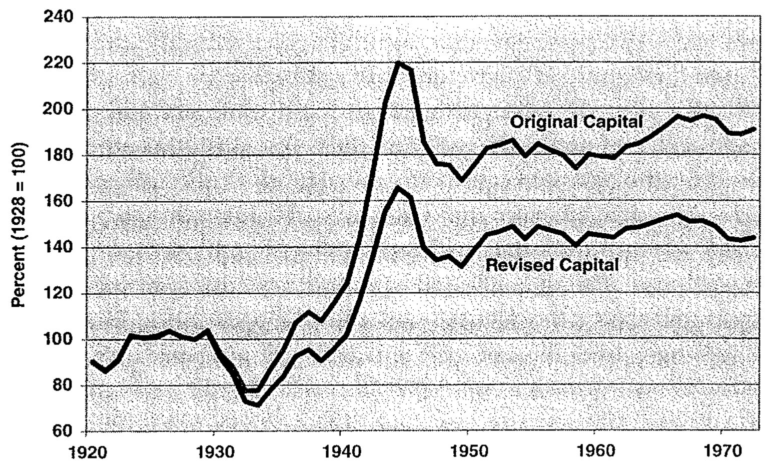

Figure 16–4. Ratio of GDP to Two Alternative Concepts of Capital Input, Original and Revised, 1920–1972

176 percent in 1950, an enormous change compared to 1928, and the average ratio between 1950 and 1972 was 185 percent.

Subsequent research summarized in the data appendix has identified three sets of measurement issues that contribute to the jump of the output-capital ratio between the 1920s and 1950s. Because mismeasurement causes capital to be understated in the 1950s relative to the 1920s, substitution of a new adjusted series on capital input raises capital in the 1950s and in tandem reduces the output-capital ratio, as shown by the lower line in figure 16–4. In contrast to the 1950 ratio of 176 percent based on the official data, that ratio in 1950 is a much lower 141 percent in the revised data. Thus roughly half of the post-1935 jump in the output-capital ratio can be attributed to the measurement issues examined in the data appendix.

Though the adjusted output-capital ratio shown as the lower line in figure 16–4 was in 1972 still 147 percent of its 1928 value, gradually the ratio fell to 108 percent by 2013. Put simply, the nation's output grew much more quickly than its capital input between 1928 and 1972 and then much more slowly from 1972 to 2013. The annualized growth rate of the output-capital ratio between 1928 and 1972 was 0.9 percent per year and then fell at –0.8 percent per year from 1972 to 2013. This history raises deep questions that we will ponder for the rest of this chapter. What factors caused the adjusted ratio to increase from 100 in 1928 to an average of 150 percent during 1950–72? Many issues await our attention, including the effect of the depression and war on production practices and industrial efficiency, as well as the underlying pace of innovation from the 1920s to the 1950s and beyond.

We now have all the ingredients needed to determine the growth history of total factor productivity (TFP), the best available measure of innovation and technological change.[15] The calculation of TFP is mechanical and equals output divided by a weighted average of labor and capital input, with standard weights of 0.7 for labor and 0.3 for capital.[16] Labor input equals aggregate hours of work multiplied by an index of educational attainment.[17] Capital input equals the adjusted concept developed in the data appendix. The resulting growth rates of TFP are displayed in figure 16–5, which displays the annual growth rate of TFP for each decade between the initial decade 1890–1900 and the extended decade 2000–2014. The horizontal labels identify the final year of each decade, and so the highest bar in the graph labeled "1950" refers to the average annual growth rate of TFP during the decade 1940–50.

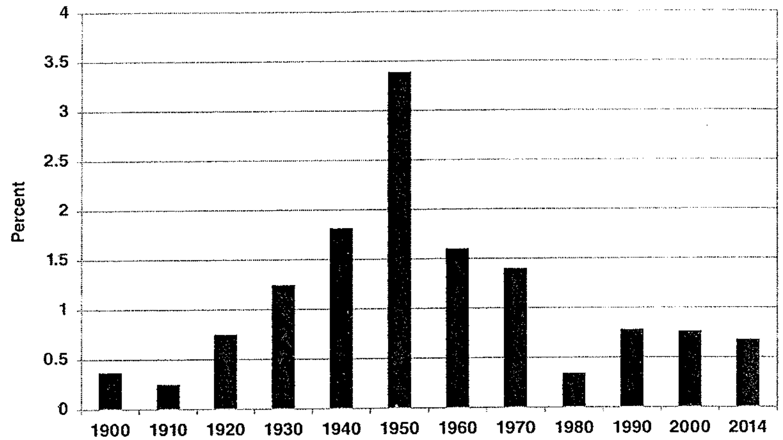

Figure 16–5. 10-Year Average Annual Growth in Total Factor Productivity, 1900–2014

Note: The average annual growth rate is over the ten years prior to year shown. The bar labelled 2014 shows the average annual growth rate for 2001–14.

This history of TFP growth has the appearance of an up-and-down "staircase" with steps of unequal height. The singularity of the 1940–50 decade leaps off the page. This graph confirms Alex Field's emphasis on the 1930s as a more productive decade than the 1920s, as well as the pickup in TFP growth in the 1920s compared to the 1890–1920 interval. Called into question is the verdict of Moses Abramowitz and Paul David (regarding World War II) that "the war . . . imposed restrictions on civilian investment, caused a serious reduction in private capital accumulation and retarded normal productivity growth."[18] Labor productivity and TFP soared during World War II, and the cessation of defense production did not prevent the wartime productivity gains from becoming permanent.

The TFP growth history laid out in figure 16–5 poses a daunting set of questions for the rest of the chapter. What was it about the innovation process that allowed TFP growth steadily to accelerate from the 1920s to 1930s to 1940s and then slow down thereafter? What was it about the growth process that allowed the *level* of TFP to remain high even after wartime production ceased in 1945–46? To what extent did the productivity explosion of the late 1930s and the 1940s benefit from inventions and innovations in the 1920s and

1930s that had a delayed impact? In the next section, the analysis begins with the effects of economic disruption in the 1930s and 1940s, and subsequently turns to the timing and effect of inventions during the first half of the twentieth century.

EXPLANATIONS ROOTED IN THE DISRUPTIONS OF THE GREAT DEPRESSION AND WORLD WAR II

What were the causes of the epochal jump in the output-capital ratio and of TFP between 1928 and 1950? To what extent could the causes be connected to the disruptions associated with the Great Depression and World War II? The first topic is the interplay between rapidly rising real wages and declining hours per week, both of which made labor more expensive to employ. The second issue is complementary, the effect of cost-cutting during the desperate decade of the 1930s that forced firms to make do with fewer employees and the high-pressure priority for maximum production during World War II that had the same effect of raising labor productivity through some combination of higher machine speeds and greater work effort. The third effect is the role of government infrastructure that was built in the 1930s and whether this would have occurred had the Great Depression not occurred.

Rising Real Wages. Earlier this chapter, we have traced the upward surge of the real wage of production workers during the 1930s and attributed it in large part to New Deal pro-labor legislation. Did the rising real wage cause a substitution away from labor toward capital? Though capital spending was depressed during the 1930s and during World War II, this was mainly true for structures (which accounted for 77 percent of the value of the capital stock in 1928). Equipment investment rebounded strongly in the 1930s. The ratio of equipment investment to the value of equipment capital was 13.6 percent in 1928 but rose above that to 14.4 percent in 1936, 16.1 percent in 1937, 15.8 percent in 1940, and 17.1 percent in 1941. At least some part of this buoyant performance of equipment investment may have represented a substitution from labor to capital that raised labor productivity. Moreover, the new capital investment of the late 1930s reflected continuing innovation. Railroad locomotives, trucks, tractors, and industrial equipment manufactured in the late 1930s were all of substantially higher quality than their counterparts of the 1920s.

The High-Pressure Economy of World War II. All the indexes of output, hours of work, and productivity soared during 1942–45. This is not surprising, for the entire economy converted to a maximum production regime in which every machine and structure was used twenty-four hours per day if enough workers could be found to staff three shifts. As shown in figure 16–2, previously, labor productivity did not exhibit even a hiccup of decline after 1945. Though hours per capita collapsed as Rosie the Riveter switched roles from factory worker to mother in the baby boom, labor productivity continued to rise farther above its 1870–1928 trend.[19]

As early as 1941 the economy was straining against a shortage of capacity in manufacturing. The capacity use rate for the steel industry reached 97 percent in 1941, as high as in any other year during World War II. Machine tools were in short supply as early as the spring of 1940, and by the spring of 1941, the owner of a leading machine tool supplier shook his head at the backlogs, stating that "the demand is infinite."[20] Though the most famous example of "learning by doing" was the drastic reduction in the number of days needed to produce a standard Liberty freighter ship built by Henry Kaiser in his Richmond, California, and Portland, Oregon, shipyards, the pressure for maximum production must have yielded permanent improvements in production techniques under conditions of war that would not have occurred in peacetime. The Kaiser shipyards began in 1942 with a schedule of fully eight months to complete a Liberty ship, but by the next year, the completion time had been reduced to a few weeks. In a unique contest between the two shipyards, an entire ship was actually put together at each yard from prefabricated parts in four days. This supreme production achievement was made possible in part by letters from more than 250 employees suggesting ways to make production more efficient.[21]

The shipyard example can be generalized to the entire manufacturing sector. Recent accounts of the Arsenal of Democracy focus not just on the Kaiser shipyards, but also on Henry Ford's mammoth factory that built B-24 bombers. The Ford plant was built in less than a year, starting in March 1941, and turned out its first plane in May 1942. The plant had originally been designed to produce bombers at the unbelievable rate of one per hour, but it was a long struggle to achieve that rate. In a classic example of learning by doing, the production rate gradually increased, reaching seventy-five per month in February 1943, 150 per month in November 1943, and a peak of 432 per month in August 1944.[22]

And the Kaiser and Ford examples were only the best known of continuous learning by doing throughout the war in the form of continuous cost reduction and efficiency improvement.

> Pontiac had reduced the cost of its complex Oerlikon anti-aircraft gun by 23 percent. Chrysler's Dodge division... engineers figured out how to make [shortwave radar systems] at 57 percent less cost than eight months earlier. The company's gyrocompasses... were costing 55 percent of the original fee.

Throughout the war, patriotism and the sense of purpose bonded workers and management together, and workers were more eager to raise efficiency (often in ways that made their lives easier) than before. The most obvious reason why productivity remained high after World War II, despite the end of the military emergency, is that *technological change does not regress.* People do not forget. Once progress is made, no matter under what circumstances, it is permanent.

The impressive performance of productivity in the late 1930s suggests that had aggregate demand collapsed after World War II as defense spending dried up, the toll would have been taken on employment rather than on productivity. But demand did not dry up; rather, it shifted almost immediately from military to civilian purchases. In 1946–47, the floodgates of demand were let loose, and after swift reconversion, manufacturers strained to meet the demand for refrigerators, stoves, washing machines, dryers, and dishwashers, not to mention automobiles and television sets. As they struggled to fill orders that seemed almost infinite, they adopted all that they had learned about efficient production in the high-pressure economy of World War II.[23]

Virtually every firm making consumer goods (except for basic food and clothing products) had been forced to make something else during World War II, and every one of these producers learned to be more efficient from the process. During the war, jewelry makers made artillery fuses, producers of lawn mowers made shrapnel shells, manufacturers of postal meters made bomb mechanisms, makers of mens' shoes made helmet liners, manufacturers of vacuum cleaners made gas mask parts, and makers of wheelbarrows shifted to production of ammunition carts for machine guns.[24] Every part of the postwar manufacturing sector had been deeply involved in making military equipment or its components, and the lessons learned from the war translated into permanent efficiency gains after the war.

Though wartime production demands may have had a permanent effect in raising the use of capital and the level of efficiency, earlier attempts to smooth the production flow and raise efficiency date back to the 1920s. Then began a deliberate managerial effort to improve use of facilities and to save on inventories of

in-process of finished products. This might help to explain the paradox of rising labor productivity and TFP growth in the 1930s despite the decline in the overall utilization of capital and labor. New methods were making it possible to raise the output-capital ratio and TFP despite low aggregate demand, helping explain why the Great Depression reduced input of labor hours more than it reduced labor productivity. This has been attributed in part to the shift in the structure of retailing to large corporations such as Marshall Field, Macy's, and Sears Roebuck, which demanded a constant flow of goods from their suppliers.[25]

There is a debate in the literature about whether World War II improved consumer welfare. Despite the prohibition of production of most durable goods, real consumption per capita (2009 dollars) remained roughly the same in 1944 as in 1941.[26] Robert Higgs has argued that the official data on real personal consumption expenditures are overstated, because the growth of true consumer prices in the wartime regime of price controls is substantially understated.[27] If the data on current-dollar consumption are correct, then any unmeasured increase in true consumer prices becomes an unmeasured decrease of the same percentage magnitude in real consumption spending. Sources of unmeasured price increases include bribes, black markets, and unmeasured declines in the quality of goods and services, including the need to wait in lines and distort consumption choices due to rationing, crowding due to migration, and a shortage of housing exacerbated by declines in rental housing maintenance due to rent controls.

Three responses to this critique range from narrow to broad. At the narrow level, the shift of 12 million people, or 9 percent of the 1940 population, into the armed forces implies that there were 9 percent fewer civilians to share the available personal consumption expenditures. Because measured real consumption was roughly the same in 1944 as in 1941, this implies that real consumption per civilian increased by 9 percent. There may well have been measurement errors, but these would have had to be greater than 9 percent for us to conclude that there was any decline in real personal consumption expenditures per member of the civilian population. All the food, clothing, and housing for the 12 million in the military (whether it be in barracks, camps, or on ships) was provided by the government and counted in wartime government spending rather than personal consumption expenditures.

A broader and more important point is that the wartime prosperity, despite its inconveniences, marked a sea change in the outlook and expectations of the entire nation after a decade of grinding depression and unemployment that appeared without end, a world of "secular stagnation" in the famous phrase of

Harvard's Alvin Hansen. The Great Depression had a searingly negative effect on the nation's sense of well-being. Through most of the 1930s, a sizable portion of the population was badly fed, clothed, and housed. This extreme poverty was eliminated by the war economy. The reduction in the economic distance between the least well-off and the rest of the population significantly lifted everyone's sense of well-being. Thus the stagnant material consumption levels of World War II may not have been thought very important for much of the population. Even if 1944 total consumption was no higher than 1941, the year 1941 seemed like paradise as it achieved a level of total real consumption fully 28 percent higher than the average annual consumption expenditures of 1930–39. Indeed, despite his negative assessment of consumer welfare in World War II, Higgs agrees with this broader point:

> The war economy...broke the back of the pessimistic expectations almost everybody had come to hold during the seemingly endless Depression. In the long decade of the 1930s, especially its latter half, many people had come to believe that the economic machine was irreparably broken. The frenetic activity of war production...dispelled the hopelessness. People began to think: if we can produce all these planes, ships, and bombs, we can also turn out prodigious quantities of cars and refrigerators.[28]

The third and even more important point is that this chapter is not about how much was produced or consumed during World War II, but rather how and why the economy was able to achieve such a "great leap" in labor productivity and total factor productivity when the 1950s are compared to the pre-1928 growth trend. The war itself may have contributed to postwar achievement directly, as explored in this section, or may, by distorting the timing of economic advance, have masked the influence of innovations and other forms of progress that were already well under way in the years leading up to 1941.

Wartime Facilities. Though private capital input stagnated during 1930–45, the amount of capital input financed by the government surged ahead throughout that fifteen-year interval. Of particular interest was the creation of new plant facilities paid for by the government but operated by private firms to produce military equipment and supplies. The wages, salaries, and profits earned in these government-owned plants were counted as part of national income originating in the private sector. Studies of productivity and TFP growth have traditionally

compared real value added in the private sector with capital input financed by the private sector, neglecting the World War II government-financed increases in the nation's stock of structures and productive equipment.[29] The starkest omission from the data on capital used in World War II product comes from a single startling fact: The number of machine tools in the U.S. *doubled* from 1940 to 1945, and almost all of these new machine tools were paid for by the government rather than by private firms.[30] Not all the government-financed facilities were in manufacturing. In 1942–44, as an emergency measure, the government financed the construction of the "Big Inch" and "Little Big Inch" petroleum pipelines over the 1,300 miles from Texas to New Jersey to provide for the safe shipment of oil in wartime conditions when the previous method of transport by sea was threatened by German submarine attacks. Both pipelines became part of the nation's postwar infrastructure and are in use to this day.

Some of the government-owned factories were on a massive and unprecedented scale. Previously we have cited learning by doing at Henry Ford's government-financed plant in Willow Run, Michigan, which at its 1944 peak was producing one bomber per hour in what was called "The World's Greatest Room." Fully 50,000 workers were employed there.[31] The feat of bringing together millions of parts and fasteners at stations extending linearly for more than half a mile was unprecedented in the history of mass production. Necessity was the mother of invention, and the Ford Willow Run plant, together with the Kaiser shipyards, stands as perhaps the most persuasive example that World War II created a permanent increase in what firms, equipment, and workers could achieve together under the pressure of a government-financed regime that guaranteed fixed markups—i.e., consistent profits—and real wages higher than any work force had known from the beginning of time. Henry Ford perhaps said it best in the epigraph that begins this chapter—in 1942–45, the production genius of the United States, led by the automobile industry, stretched its imagination to perform feats never before imagined, but after imagination took over and the wartime goals were achieved, the economy did not forget.

LONG-TERM EXPLANATIONS: URBANIZATION, THE CLOSED ECONOMY, AND THE IMPROVEMENT OF CAPITAL QUALITY

Urbanization and the Decline of Farming. Now we turn to the complementary set of explanations of the great leap forward that do not rely on specific events related to the Great Depression or World War II. In searching for explanations of the rapid growth of TFP after 1929, we start with urbanization, which by moving workers from less productive agricultural jobs to more productive urban occupations contributes to the economy-wide advance of TFP growth. Did urbanization advance at a quicker pace between 1920 and 1960 than it had before or has since? The urban share during the slow productivity growth period of 1890–1920 grew from 35.1 percent to 50.8 percent. From 1920 to 1960, it rose from 50.8 percent to 69.7 percent, about the same rate per decade. Thus urbanization by itself does not explain the post-1928 acceleration in productivity and TFP growth.

Immigration and Imports. Between 1870 and 1913, roughly 30 million immigrants arrived on American shores; they crowded into central cities but also populated the Midwest and the plains states. They made possible the rapid population growth rate of 2.1 percent per year over the same interval, and the new immigrants created as much demand as supply in the sense that there was no mass unemployment caused by their arrival—and in fact the unemployment rate in 1913 was only 4.3 percent.[32] All those new people required structures to house them, factories to work in, and equipment inside the factories, so the new immigrants contributed to the rapid rise of capital input.

Contrast this with the shriveling up of immigration after the restrictive immigration laws of 1921 and 1924.[33] The ratio of annual immigration to the U.S. population dropped from an average 1.0 percent per year during 1909–13 to 0.25 percent per year during 1925–29, and the growth rate of the population fell from 2.1 percent during 1870–1913 to 0.9 percent between 1926 and 1945.[34] The anti-immigration legislation has long been cited as a cause of the Great Depression, in the sense that the overbuilding of residential and nonresidential structures in the 1920s was based on an expectation of continued rapid population growth that did not occur.[35]

Both the immigration legislation and the draconian regime of high tariffs (the Ford–McCumber tariff of 1922 and the Smoot–Hawley tariff of 1930) converted the U.S. into a relatively closed economy during the three decades between 1930 and 1960. The lack of competition for jobs from recent immigrants made it easier for unions to organize and push up wages in the 1930s. The high tariff wall allowed American manufacturing to introduce all available innovations into U.S.-based factories without the outsourcing that has become common in the last several decades. The lack of competition from immigrants and imports boosted the wages of workers at the bottom and contributed to the remarkable "great compression" of the income distribution during the 1940s, 1950s, and 1960s.[36]

Thus the closing of the American economy through restrictive immigration legislation and high tariffs may indirectly have contributed to the rise of real wages in the 1930s, the focus of innovative investment in the domestic economy, and the general reduction of inequality from the 1920s to the 1950s.

CAN THE INNOVATIONS OF THE 1920s AND 1930s EXPLAIN THE GREAT LEAP?

Our account in part I of this book of the great inventions distinguishes between the original invention and the subsidiary subinventions made possible by the initial invention. The two most important inventions of the late nineteenth century were electric light and power and the internal combustion engine, and these are often described as a "General Purpose Technology" (GPT) that can lead to the creation of many subinventions.[37]

Subinventions made possible by electricity as a GPT are such fundamental drivers of productivity as elevators; electric hand and machine tools; electric streetcars, elevated trains, and underground subways; the whole host of consumer appliances starting with the electric iron and vacuum cleaner and followed by the refrigerator, washing machine, clothes dryer, dishwasher, and many others; and, finally, air conditioning, which arrived in movie theaters in the 1920s, in some office buildings in the 1930s, and in the American home in the 1950s and 1960s. A similar list of subinventions made possible by the internal combustion engine as a GPT includes the car, truck, bus, and taxi; supermarkets; suburbs; and all the aspects of personal travel, including motels and roadside restaurants, as well as air travel.

Though we have no need to choose between electricity and the internal combustion engine as the most important GPT of all time, an author in 1932 provided a persuasive case that the most important invention of all time was the discovery of how to transform mechanical power into electricity, which then could be transported by wires for long distances and then retransformed into whatever form of energy might be desired. This passage is interesting also for its perspective on how much of the modern world had already been invented at the time of its writing in 1932.

> Without it not only would the street car again be horse-drawn, but the automobile and the airplane would stop. For without electromagnetic sparking devices, how could gasoline engines function? The electric

light would, of course, disappear, and with it the greatest guarantee of safety after twilight in the great cities. The telephone and telegraph would be idle, and the daily newspaper would therefore become of merely local interest... Radiotelegraphy, telephony, and broadcasting would all disappear. Power plants would have to be associated with every separate factory, because long-distance transmission of power would cease. The rivers could furnish power only to factories situated on their banks.... Hospital practice would again be without X-ray appliances, and households would be without electric work-lightening devices. Ships in distress at sea, no longer able to signal their S O S calls and no longer provided with gyrocompass, radio direction finding, or fire-signaling apparatus, would often sink, as formerly, with none to rescue or help.[38]

Those attempting to explain the great leap forward in terms of inventions often cite Alfred Kleinknecht (1987), who counted up inventions by decade and declared that the decade with the greatest number of important inventions was the 1930s. In fact, if we include the 1920s, 1930s, and 1940s, these three decades contributed twenty-six out of the thirty-nine most important inventions in Kleinknecht's list of the twelve decades between 1850 and 1970. My reading of the history of invention suggests the reverse—that the 1930s were distinguished by subsidiary subinventions rather than the discovery of fundamental GPTs. For instance, the 1930s were a defining decade in the perfection of the piston-powered military and commercial aircraft, but this was not a new GPT. It represented the marriage of the 1879 invention of the internal combustion engine with the 1903 aerodynamic design of the Wright Brothers that made possible the first flight. Similarly, the invention of television in the 1920s and 1930s combined the 1879 invention of wireless transmission with the 1907 Lee De Forest invention of the vacuum tube which had previously made commercial radio possible.

Alexopoulos and Cohen (2010) have made an important contribution to the history of innovation, although their study is limited to 1909–49. They criticize the use of patent data as a measure of the pace of innovation for two basic reasons—because the date of the basic invention may be decades earlier than the introduction of a commercially viable version and because a patent provides no information about the future commercial viability of the idea.[39] Instead, they conduct an exhaustive search of the Library of Congress catalogue for handbooks and other books about technology and compare the date of the first book(s) on an innovation with its date of initial commercialization. Their count supports Field's emphasis on the 1930s, especially after 1934, as a period having a larger count of technical books published than any other interval in their forty-year period. The average number was between 500 and 600 between 1911 and 1934, then soared monotonically to 930 in 1941 and averaged about 750 between 1942 and 1949.[40]

Worthy of consideration as a GPT is Henry Ford's introduction of the assembly line to automobile manufacture, dating from December 1, 1913.[41] Developed from the ideas of many predecessors, dating back to Richard Garrett's 1853 English steam engine factory, the assembly line revolutionized manufacturing and deserves equal credit with electric motors for achieving the acceleration of TFP growth which began in the 1920s (as is evident in figure 16–5). Moses Abramowitz and Paul David attribute the rapid spread of the techniques of mass production to Ford's "deliberate policy of openness" about his detailed methods of operation that "contributed to the rapid diffusion of these new techniques throughout American manufacturing."[42] It is interesting to contrast the very slow arrival of electric motors in manufacturing as emphasized by the same David as contrasted to the rapid diffusion of the assembly line technique.

The assembly line, together with electric-powered tools, utterly transformed manufacturing. Before 1913, goods were manufactured by craftsmen at individual stations that depended for power on steam engines and leather or rubber belts. The entire product would be crafted by one or two employees. Compare that with a decade later, when each worker had control of electric-powered machine tools and hand tools, with production organized along the Ford assembly-line principle. An additional aspect of the assembly line was that it saved capital, particularly "floor space, inventories in storage rooms, and shortening of time in process."[43]

It is likely that electric power and the assembly line explain not just the TFP growth upsurge of the 1920s, but also that of the 1930s and 1940s. There are two types of evidence that this equipment capital was becoming more powerful and more electrified. First is the horsepower of prime movers, a data series available for selected years for different types of productive capital, and the second is kilowatt hours of electricity production. Analysts have long emphasized the role of both horsepower and electricity use as explanations of high productivity in American manufacturing relative to other nations.[44] Table 16–2 displays on the

Table 16–2. Horsepower of Prime Movers and Kilowatt Hours of Net Production of Electric Energy, 1929=100, Selected Years 1899–1950

	1899	**1909**	**1919**	**1929**	**1940**	**1950**
(1) Variable Depreciation Private Equipment Capital in 1950 Dollars	34	57	82	100	120	164
Horsepower						
(2) Automotive	0	1	16	100	176	309
(3) Factories	49	84	101	100	110	170
(4) Farms	13	34	76	100	156	231
(5) Electric Central Stations	5	13	33	100	134	220
(6) Average of Auto, Factories, Farms	20	40	64	100	147	237
(7) Ratio of Horsepower to Equipment Capital	61	70	79	100	123	145
	1902	**1912**	**1920**	**1929**	**1941**	**1950**
(8) Variable Depreciation Private Equipment	39	63	84	100	123	164
Kilowatt Hours						
(9) Industrial Establishments	14	54	70	100	177	242
(10) Electric Utilities	3	13	43	100	178	357
(11) Total	5	21	48	100	178	333
(12) Ratio to Equipment Capital	13	34	58	100	145	203

Sources: HSUS Colonial Times to 1957, Series S2, S6, S11, S13, S19, and S33.
Variable Depreciation Private Equipment Capital from the data underlying Figure 16–4.

top line for selected years the constant-dollar value of private equipment capital developed in the data appendix.[45]

Total horsepower is shown as an index number (1929=100) for four categories of equipment: automotive, factories, farms, and electric central stations. In absolute magnitude, the horsepower installed in the nation's fleet of vehicles swamped every other type of equipment capital, but unfortunately, the horsepower data do not distinguish automobiles used for personal travel from those used for business travel, nor from trucks and buses. Milestones for automotive horsepower include the surpassing of the horsepower of work animals by 1910 and of railroads by 1915. Horsepower in factories increased much more slowly, and the index numbers for 1940 and 1950 are very similar to those for the private equipment series. A puzzling aspect of the factory horsepower data is the absence of any growth in the 1920s. Horsepower on farms and in electric generating stations increased more rapidly than private equipment after 1929.

Because any index of total horsepower is swamped by the automotive category, we take a simple arithmetic average of the index numbers for automotive, factories, and farms, omitting electric utility generation on the ground that it is an intermediate good rather than private investment. The ratio of horsepower to equipment capital, shown on line 7 of table 16–2, rose modestly by 13 percent per decade during 1899–1919, then accelerated to 24 percent per decade in the 1920s, 21 percent in the 1930s, and 17 percent in the 1940s.

Unlike the horsepower series, which starts out with a substantial base of installed steam power in 1899, the kilowatt-hour series starts from zero in 1882 and thus would be expected to exhibit the fastest growth rates in its early years. Nevertheless, impressive growth is registered in the 1930s and 1940s. Particularly noteworthy is the series on electricity generated by industrial establishments, which grew by 57 percent between 1929 and 1941, more quickly than the 36 percent of the 1920s or 31 percent of the 1940s. When expressed as a ratio to private equipment capital, the growth rate of industry-generated electricity grew at 18 percent in the 1920s, 36 percent in the 1930s, and only 3 percent in the 1940s. The ratio of total kilowatt hours, most of which was generated by electric utilities, to private equipment capital grew at 54 percent in the 1920s, 37 percent in the 1930s, and 34 percent in the 1940s.

Overall, the increase in the horsepower of motor vehicles and the use of electricity rose much more quickly than did equipment capital in the 1930s and 1940s. While the stock of private equipment rose by 50 percent (in logs) between 1929 and 1950, motor vehicle horsepower tripled and total electricity production rose by 3.3 times. Total registrations increased between 1929 and 1941 by 45 percent for trucks and more than tripled for buses. All these additional trucks and buses were much more powerful in 1941 than they had been in 1929. Though we do not have separate horsepower data for trucks and buses, we learned above in table 5–2 that automobile horsepower in a typical popular low-priced car increased from twenty horsepower in Ford's Model T, which dominated the 1913–25 interval, to forty horsepower in Ford's Model A, introduced in 1928, to eighty-five horsepower in the 1940 Chevrolet. The horsepower of trucks and buses must have increased at comparable rates.[46]

Field finds that the most important industries contributing to the productivity upsurge of the 1930s were manufacturing and transportation/distribution. This chapter thus far has pointed to two separate sources of productivity growth in transportation/distribution, the heavy government investment in highways, and the much higher horsepower of the nation's trucking fleet in 1941 compared to 1929. The rapid rise of electricity production after 1929 by industrial enterprises provides solid evidence that the use of electricity by industrial machinery grew rapidly during the 1930s and contradicts Field's judgment that the 1930s represented the "tail end" of the "electrification transition."[47] Higher electricity use in the 1930s reflected the continuing adaptation to electric equipment not just in manufacturing, but also in the form of refrigerated cases in wholesaling and retailing and the widespread use of electric production methods in the rest of the economy, including the earliest examples of air-conditioned movie theaters and office buildings.[48]

The great expansion of electricity production in the 1930s and 1940s was made possible by economies of scale, for larger electric-generating boilers produced electricity at a lower unit cost. Throughout the 1930s and 1940s, increasing size was combined with higher temperatures and pressures as technology made tightly sealed boilers more reliable.[49] The evolution of higher thermal efficiency and productivity in the electric utility example is an example not of a breakthrough invention but of "incremental tinkering," a constant striving to improve existing technology. Totally new inventions as well as incremental tinkering are the fundamental sources of growth in TFP, and the data do not allow us to distinguish between them.

Beyond the productivity-enhancing role of electricity and the internal combustion engine, which innovations drove productivity growth in the 1930s and 1940s? The distribution system was revolutionized by the movement to chain stores and self-service stores that started around 1910 and continued during the 1920s and 1930s. The number of chain food stores quadrupled during the 1920s, achieving a major boost to productivity. But chain stores initially operated by the old-fashioned "counter and shelf" system in which the customer stood in line at each separate department and the clerk both selected the item from the shelf and received payment. It was when chain stores developed self-service, much of which happened after 1930, that the real productivity gains occurred as the customers did the walking and selecting, and the number of employees needed to run a store fell by half or more.

As important as was progress in the transportation and distribution industries, innovation and discoveries exploded after 1929 in the petroleum and related chemical industries. An epochal moment in the history of the American petroleum industry occurred with the discovery, in October 1930, of the east Texas oil field, which has been called "the largest and most prolific oil reservoir in the contiguous United States."[50] The chemicals industry, dominated by German firms in the late nineteenth century, took off in the U.S. in the 1930–50 period. Many types of plastics had been invented before 1930. Among these were celluloid (1863), polyvinyl chloride (1872), cellophane (1908), bakelite (1909), and vinyl (1927). But the timeline of plastics inventions highlights the 1930s as perhaps the most fruitful innovative period in the history of the industry, with polyvinylidene chloride (1933), low-density polyethylene (1935), acrylic methacrylate (1936), polyurethanes (1937), polystyrene (1938), Teflon (1938), nylon (1939), and neoprene (1939). Of all the inventions on the plastics timeline, five were invented between 1839 and 1894, four more between 1894 and 1927, and seven in the brief period 1933–39.[51] Field lists numerous practical byproducts of developments in the chemical industries in the 1930s, including coatings that doubled the lives of railroad ties, quick-drying lacquers that reduced the time required to paint a car from a few weeks to a few hours, and the introduction of stainless steel and chrome. Plastics often saved fuel, fabrication, and capital costs.[52]

The productivity of motor vehicles depended not only on the power of their engines, which increased rapidly from 1920 to 1940, but also on the quality of their tires. Advances in rubber technology made it possible to equip trucks and tractors with larger and more durable tires. In fact, the early 1930s were the period when tractors became powerful enough, and their tires became large enough, to allow the revolution in agricultural productivity which they made possible. Field conjectures about the role of larger engines and better tires, along with the first (pre-interstate) national highway system, in allowing trucks to begin in the 1930s to compete with rail as a carrier of the nation's freight.[53]

A much more prosaic but very important improvement happened in the 1920s that represents a potential source of productivity gains. The "American manufacturing system" had always been known for standardization and its ability to turn out identical components of a product. In chapter 2, we recorded the marvel of European observers at the 1851 Crystal Palace expedition of the American achievement: "Almost all of the American machines did things that the world earnestly wished machines to do."[54] But standardization of parts was not achieved in 1851. There was a proliferation of multiple products for which the purpose was identical; in 1917 it was disclosed that the number of different varieties of single-bit ax offered for sale in the United States to chop down a tree was 994,840. "In this wide range were thirty-four models, four grades, thirty-five brands, eleven finishes, and nineteen sizes."

One of the most important improvements in American industrial efficiency was the establishment by Herbert Hoover of the National Bureau of Standards. Its aim was to create a system of uniformly sized parts, down to screws and bolts, aimed at "simplification of practice, elimination of waste, conservation of materials, minimum training of workers, reduction and savings in supply purchasing and unwieldy inventories, defeat of confusion, and speed in production."[55] One of the triumphs of standardization was the production of millions of universal joints during World War II, required to transform uniform velocity from the driving to the driven shaft of high-speed vehicles. Standardization of parts allowed the Bendix design for these joints to be manufactured by twenty-three additional companies that had no previous experience. An enormous improvement of industrial efficiency was made possible by standardization of such mundane components as nuts, bolts, and screws and the drive to standardization that had begun in the 1920s.[56]

CONCLUSION: WHAT CAUSED THE GREAT LEAP FORWARD?

The most fundamental question of modern economic history is why after two millennia of no growth at all in per capita real output from Roman times to 1750, economic growth moved out of its hibernation and began to wake up.[57] More relevant for our times is the second most important question, why growth has slowed since the 1960s and early 1970s not only in the United States and Japan, but also in much of western Europe. Though the timing of economic growth in Japan and Europe was different as a result of wartime destruction and interwar economic disruption, the slowdown is real; indeed, during the past two decades, labor productivity in the European Union has grown at half the pace of the United States. The third question is the focus of this chapter, why U.S. economic growth was so rapid during the middle of the twentieth century, particularly between 1928 and 1950.

The topic of this chapter focuses on the timing of U.S. economic growth and is as simple as it is perplexing. Why does a decadal plot of growth in U.S. labor productivity and TFP since 1890 look like a trek over a mountain, gradually ascending to the decade of the 1940s and gradually descending since then? The second and third questions are intertwined, for the post-1972 growth slowdown is considered a disappointment precisely because the pace of growth during 1928–72 was so rapid and so unprecedented.

The answers to both the second and third questions are fundamental to this book. This chapter has sought to quantify and then determine the causes of the great leap of labor productivity and TFP growth between the late 1920s and early 1950s, thus accounting for how TFP growth in the decades of 1930–40 and 1940–50 outpaced any others in American history. What was so special about that two-decade interval in which normal economic activity was disrupted by the Great Depression and World War II?

There are many possible explanations, and it is impossible to rank the quantitative importance of most. However, throughout this chapter, we have been able to rule out several potential causes. Education is ruled out, for the secular advance in educational attainment was just as important between 1910–28 and 1950–72 as between 1928–50. Similarly, the shift of Americans from rural farms and small towns to urban life in places having more than 2,500 population proceeded, if anything, slightly slower during 1928–50 than it had between 1870 and 1928.

The most novel aspect of this chapter is its suggestion that the Great Depression and World War II directly contributed to the great leap. Had there been no Great Depression, there probably would have been no New Deal, with its NIRA and Wagner Act that promoted unionization and that directly and indirectly contributed to a sharp rise in real wages and a shrinkage in average weekly hours. In turn, both higher real wages and shorter hours helped to boost productivity growth rapidly in the late 1930s, before the United States entered World War II. Substitution from labor to capital as a result of the jump in the real wage is evident in the data on private equipment investment, which soared in 1937–41 substantially above the equipment investment:capital ratio of the late 1920s.

Another more subtle effect of the Great Depression may have been the reorganization of business after the sharp drop in output and profits generated severe cost-cutting, most notably in the dismissal of employees. Yet output did not fall to zero in the 1930s, and the output that was produced with a lower number of employees reflected new ideas and techniques of efficiency, many of them carried over from the 1920s. Our evidence on the horsepower of motor vehicles, which greatly increased over the 1930s, suggests that the power and efficiency of electric machine tools and hand tools may have similarly experienced a substantial improvement in the 1930s.[58] Indeed, our evidence in table 16–2 implies that there was a sustained increase during 1929–50 in horsepower per unit of constant-cost capital equipment, as well as a vast increase in the amount of electricity consumed per unit of capital.

Less speculative is the productivity-enhancing learning by doing that occurred during the high-pressure economy of World War II. Economists have long studied the steady improvement over time in the speed and efficiency with which Liberty freighter ships were built. The most remarkable aspect of the surge in labor productivity during World War II is that it appears to have been permanent; despite the swift reduction in wartime defense spending during 1945–47, labor productivity did not decline at all during the immediate postwar years. The necessity of war became the mother of invention of improved production techniques, and these innovations, large and small, were not forgotten after the war.

In addition to the increased efficiency of existing plant and equipment, the federal government financed an entirely new part of the manufacturing sector, with newly built plants and newly purchased productive equipment. The high level of postwar productivity was made possible in part because the number of machine tools in the U.S. *doubled* between 1940 and 1945.[59] The amount of additional productive equipment that the federal government purchased to produce private sector output was staggering. Between 1940 and 1945, the federal government purchased productive equipment that amounted to roughly 50 percent of the stock of privately owned equipment that existed before the war in 1941.[60] And because it was all purchased between 1941 and 1945, this capital was more modern and productive than the stock of privately owned capital that existed in 1941.

Going beyond explanations that emerge from the sequence of the Great Depression followed by World War II, we need to consider the pace of innovation itself. Perhaps the most important source of the Great Leap Forward was the increased quality of machinery, as represented by the large increases in horsepower and kilowatt-hour of electricity usage per dollar of equipment capital. For every 100 units of electricity that were added to the productive process during 1902–29, another 230 units were added between 1929 and 1950. Paul David has rightly emphasized the long delay between the first electric power station in 1882 and the revolution in manufacturing productivity in the early 1920s. But this focus on the 1920s as the breakthrough decade misses that the full force of electricity expansion in manufacturing and the rest of the economy took place between 1929 and 1950.

The trauma of the Great Depression did not slow down the American invention machine. If anything, the pace of innovation picked up in the last half of the 1930s. This is clear in the data assembled by Alexopoulos and Cohen

on technical books published. The dominance of the 1930s, or more generally the period 1920–1950, is supported by Kleinknecht's count of inventions by decade. Previous chapters have provided evidence of rapid progress in radio, the quality of motion pictures, and a sharp jump in the quality of motor cars. By 1940, automobile manufacturers had achieved the dream of producing automobiles that could go as quickly as the highways would allow them to travel; the development of highways worthy of this technical marvel would wait until the construction of the interstate highway system, largely achieved during 1958–72.

Little attention has been paid in this book to oil and plastics, for these are intermediate goods. However, from the discovery of the east Texas oil field to the development of many types of plastics now considered commonplace, the 1930s added to its luster as a decade of technological advance. The use of plastics in every kind of producer and consumer durable was on the cusp of reality in 1941 before production was diverted to wartime uses. A favorite photograph of the hardships of the World War II home front shows women painting stripes on their legs to replace the rayon and nylon stockings that were no longer available.

Two overriding conclusions emerge from this study of one of the great puzzles of economic growth. First, World War II saved the U.S. economy from secular stagnation, and a hypothetical scenario of economic growth after 1939 that does not include the war looks dismal at best. Second, much more than in traditional economic history, the Great Inventions of the late nineteenth century, especially electricity and the internal combustion engine, continued to alter production methods beyond recognition not just in the 1920s but in the 1930s and 1940s as well. Alex Field revitalized U.S. economic history by his startling claim that the 1930s were the "most progressive decade." For us to determine that labor productivity and TFP growth were even quicker during 1941–50 does not diminish the boldness of Field's imagination with his claim or the depth of evidence that he has marshaled to support it.[61]

Chapter 17

INNOVATION: CAN THE FUTURE MATCH THE GREAT INVENTIONS OF THE PAST?

We wanted flying cars, instead we got 140 characters.

—Peter Thiel

INTRODUCTION

The epochal rise in the U.S. standard of living that occurred from 1870 to 1940, with continuing benefits to 1970, represent the fruits of the Second Industrial Revolution (IR #2). Many of the benefits of this unprecedented tidal wave of inventions show up in measured GDP and hence in output per person, output per hour, and total factor productivity (TFP), which as we have seen grew more rapidly during the half-century 1920–70 than before or since. Beyond their contribution to the record of measured growth, these inventions also benefited households in many ways that escaped measurement by GDP along countless dimensions, including the convenience, safety, and brightness of electric light compared to oil lamps; the freedom from the drudgery of carrying water made possible by clean piped water; the value of human life itself made possible by the conquest of infant mortality; and many others.

The slower growth rate of measured productivity since 1970 constitutes an important piece of evidence that the Third Industrial Revolution (IR #3) associated with computers and digitalization has been less important than IR #2. Not only has the measured record of growth been slower since 1970 than before, but, as we have previously suggested, the unmeasured improvements in the quality of everyday life created by IR #3 are less significant than the more profound set of unmeasured benefits of the earlier industrial revolution. Though there has been continuous innovation since 1970, it has been less broad in its

scope than before, focused on entertainment and information and communication technology (ICT), and advances in several dimensions of the standard of living related to food, clothing, appliances, housing, transportation, health, and working conditions have advanced at a slower pace than before 1970.

This chapter addresses the unknown future by examining closely the nature of recent innovations and by comparing them with future aspects of technological change that are frequently cited as most likely to boost the American standard of living over the next few decades. Innovation is proceeding apace, and almost weekly the stock market rewards newly created firms with initial public offering (IPO) valuations of a billion dollars or more. There is no debate about the frenetic pace of innovative activity, particularly in the spheres of digital technology, including robots and artificial intelligence. Instead, this chapter distinguishes between the *pace* of innovation and the *impact* of innovation on the growth rates of labor productivity and TFP.

The chapter begins with a historical overview of the source of inventions since 1870 and emphasizes a U-shaped history in which the role of the individual inventor dominated the late nineteenth century, followed by most of the twentieth century, when major inventions occurred within the research laboratories of giant corporations. After 1975, the individual entrepreneur returned as the modern electronic age was created by individuals such as Bill Gates, Steve Jobs, and Mark Zuckerberg.

Equipped with this historical background, we then examine the quantitative record of progress. The post-1970 years have not witnessed a uniformly slow advance of TFP. Instead the impact on TFP of the inventions of IR #3 were centered on the decade 1994–2004. We describe changes in business practices in the office, in the retail sector, and in the banking and financial sector and find in all cases that current methods of production had been largely achieved by 2004. Along numerous quantitative measures that compare the 1994–2004 decade with the recent past, we find a marked slowing down, leading to the suggestion that the wave of innovation in the late 1990s may have been unique, unlikely to be repeated over our forecasting horizon of the next quarter-century.

The chapter then looks into the future, providing numerous historical examples in which forecasts of the future development of technology turned out to be relatively accurate. We focus on the development of robots and artificial intelligence and assess the forecasts made by "techno-optimists" that the U.S. economy is on the verge of a new surge of productivity growth at the cost of massive future job destruction, as robots replace large numbers of jobs, and as highly sophisticated computer algorithms eliminate analytical jobs from legal searches to personal financial analysis. The chapter concludes with an alternative version of the future in which the job destruction by robots and artificial intelligence proceeds slowly, just as it has over the past several decades. The economy will be able to maintain relatively full employment as the fruits of computerization cause the composition of job types and categories to evolve only slowly rather than in a great rush. The rate of advance of labor productivity and TFP over the next quarter century will resemble the slow pace of 2004–15, not the faster growth rate of 1994–2004, much less the even faster growth rate achieved long ago during 1920–70.

INNOVATION THROUGH HISTORY: THE ULTIMATE RISK-TAKERS

The entrepreneurs who created the great inventions of the late nineteenth century—not just Americans, including Thomas Edison and the Wright Brothers, but also foreigners such as Karl Benz—deserve credit for most of the achievements of IR #2, which created unprecedented advances in the American standard of living in the century after 1870. Individual inventors were the developers not just of new goods, from electric light to the automobile to processed corn flakes to radio, but also of new services such as the department store, mail-order catalog retailing, and the motel by the side of the highway. Although this book's coverage begins in 1870, we should not neglect the role of individuals before that year. Among the Americans notable for pre-1870 inventions are Samuel F. B. Morse for his 1844 invention of the telegraph and Cyrus McCormick for his 1834 invention of the reaper. They were preceded by many British inventors going back to Thomas Newcomen and James Watt (the inventors of the steam engine) and George Stephenson (who shares in the invention of the railroad).

Most studies of long-term economic growth attempt to subdivide the sources of growth among the inputs, particularly the number of worker-hours and the amount of physical capital per worker-hour, and the "residual" that remains after the contributions of labor and capital are subtracted out. That residual, defined initially in Robert Solow's pioneering work of the 1950s, often goes by its nickname "Solow's residual" or by its more formal rubric "total factor productivity" (TFP). Though primarily reflecting the role of innovation and technological change, increases in TFP also respond to other types of economic change going beyond innovation, for instance the movement over time of a large percentage of the working population from low-productivity jobs on the farm to higher-productivity jobs in the city. Solow found, to his own surprise and to others', that only 13 percent of the increase in U.S. output per worker between 1910 and 1950 resulted from an increase in capital per worker; this famous result seemed to "take the capital out of capitalism."

The usual association of TFP growth with innovation misses the point that innovation is the ultimate source of all growth in output per worker-hour, not just the residual after capital investment is subtracted out. Capital investment itself waxes and wanes depending not just on the business cycle but also on the potential profit made possible by investing to produce newly invented or improved products. Without innovation, there would be no accumulation of capital per worker. As Evsey Domar famously wrote in 1961, without technical change, capital accumulation would amount to "piling wooden plows on top of existing wooden plows."[1]

Technological change raises output directly and induces capital accumulation to create the machines and structures needed to implement new inventions. In addition, innovations are the source of improvements in the quality of capital—for example, the transition from the rotary-dial telephone to the iPhone, or from the Marchant calculator to the personal computer running Excel. The standard technique of aggregating capital input by placing a higher weight on short-lived capital such as computers than on long-lived capital like structures has the effect of hiding inside the capital input measure the contribution of innovation in shifting investment from structures to computers.[2]

This leaves education and reallocation as the remaining sources of growth beyond innovation itself. However, both of these also depend on innovation to provide the rewards necessary to make the investment to stay in school or to move from farm to city. This is why there was so little economic growth between the Roman era and 1750, as peasant life remained largely unchanged. Peasants did not have an incentive to become educated, because before the wave of innovations that began around 1750, there was no reward to the acquisition of knowledge beyond how to move a plow and harvest a field. Similarly, without innovation before 1750, the reallocation of labor from farm to city did not happen. It required the innovations that began in the late eighteenth century and that created the great urban industries to provide the incentive of higher wages to induce millions of farm workers to lay down their plows and move to the cities.[3]

Thus every source of growth can be reduced back to the role of innovation and technological change. Pioneers in the development of particular products and industries have been described by Schumpeter as "innovators," those "individuals who are daring, speculative, restless, imaginative and, more pertinently, eager to exploit new inventions."[4] Thus innovators, particularly when acting by themselves or in small partnerships, are the ultimate risk-takers. Their inventions may lead them to create large firms, or their inventions may be supplanted by alternatives that are more efficient and perform better. Or they may have a promising idea and fail to find a source of funding for development of that idea. Invention at the level of the individual "is anything but mechanical, automatic, and predictable. Chance plays a tremendous role."[5]

Few descriptions of the role of risk and chance in the process of invention are as evocative as that of D. H. Killeffer, writing in 1948:

> Inventions do not spring up perfect and ready for use. Their conception is never virginal and must be many times repeated. One seldom knows who the real father is. The period of gestation is long with many false pains and strange forebirths.... Few of the children of the mind ever survive and those only after many operations and much plastic surgery.[6]

William Baumol offers a related caution. Entrepreneurs contribute to economic growth far more than the narrow word "innovation" can convey.

The explosion of U.S. entrepreneurial innovation after the Civil War is documented in figure 17–1, which displays the ratio of patents relative to the total population from 1790 to 2012. The large jump in patents during the 1860–1880 period coincides with the dates of the great inventions of the second industrial revolution, including electric light and power (1879, 1882), the telephone (1876), and the internal combustion engine (1879). Patents per capita remained at a plateau over the interval between 1870 and 1940. There was then a dip through 1985 followed by an explosion, particularly after 1995. Average ratios in figure 17–1 over successive intervals are 18 for 1790–1830, 89 for 1830–1870, 344 from 1870 to 1940, 275 from 1940 to 1985, and then 485 from 1985 to 2012.

The last three decades of the nineteenth century were the glory years of the self-employed American entrepreneur/inventor. Horatio Alger–like fantasies were conjured up by the concrete achievements of inventors like Bell and Edison, whose names were widely known and whose latest inventions were publicized and discussed. The goal of becoming an individual entrepreneur, a

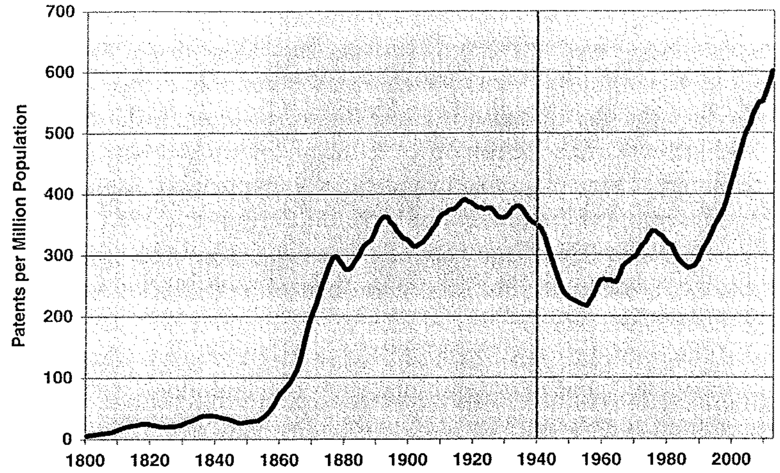

Figure 17–1. U.S. Patents Issued Per Million Population, 10 year Moving Average, 1800–2012

Source: www.uspto.gov/web/offices/ac/ido/oeip/taf/h_couints.pdf, column labeled "Utility Patents (Inventions)."

"self-made man," excited dreams of young men, even if few would be able to follow the steps of social mobility pioneered by Edison. Nevertheless, many of the manufacturing firms of this era were founded by owners who had begun as ordinary workers. To start one's own business—that is, to be an entrepreneur—was a badge of success; to remain a mere employee "was to forsake a life of striving for a condition of dependency—itself a sign of moral failing."[7]

The U-shaped interpretation of entrepreneurial history starts with a primary role for individual entrepreneurs, working by themselves or in small research labs like Edison's.[8] By the 1920s, the role of the individual entrepreneur reached the bottom part of the U, as innovation came to be dominated by employees working for large corporate research laboratories. Much of the early development of the automobile culminating in the powerful Chevrolets and Buicks of 1940–41 was achieved at the GM corporate research labs. Similarly, much of the development of the electronic computer was carried out in the corporate laboratories of IBM, Bell Labs, and other large firms. The transistor, the fundamental building block of modern electronics and digital innovation, was invented by a team led by William Shockley at Bell Labs in late 1947.[9] The corporate R&D division of IBM pioneered most of the advances of the mainframe computer era from 1950 to 1980. Improvements in consumer electric appliances occurred at large firms such as General Electric, General Motors, and Whirlpool, while RCA led the early development of television.

But then the process began to climb the right side of the U as the seminal developments of the transition from mainframes to personal computers and the Internet were pioneered by individual entrepreneurs. A pivotal point in this transition was the decision of IBM, the developer in 1981 of the first widely purchased personal computer, to farm out not just the conception of the operating system software, but also the ownership of that software, to two young entrepreneurs, Paul Allen and the Harvard dropout Bill Gates, who had founded Microsoft in 1975. The Third Industrial Revolution, which consists of the computer, digitalization, and communication inventions of the past fifty years, has been dominated by small companies founded by individual entrepreneurs, each of whom created organizations that soon became very large corporations. Allen and Gates were followed by Steve Jobs at Apple, Jeff Bezos at Amazon, Sergei Brin and Larry Page at Google, Mark Zuckerberg at Facebook, and many others.

The left side of the entrepreneurial U is well documented. The percentage of all U.S. patents granted to individuals (as contrasted with business firms) fell from 95 percent in 1880 to 73 percent in 1920, to 42 percent in 1940, and then gradually to 21 percent in 1970 and 15 percent in 2000. Of the remainder, until 1950, almost all were granted to U.S. firms, but after 1950, the share going to foreign firms soared until in 2000 the 85 percent not granted to individuals were divided almost evenly, with 44 percent going to U.S. firms and 41 percent to foreign firms. Nicholas attributes the decline in the share of independent invention to the growth of "complex capital-intensive areas such as chemicals and electricity."[10]

The declining role of individuals occurred not just because of the increased capital requirements of ever more complex products, but also because the individuals who developed the most successful products formed large business enterprises, including Bell, Edison, and Ford, among many others. Edison's early light bulb patents ran out in the mid-1890s, leading to the establishment of General Electric laboratories to develop better filaments. By the same time Bell's initial telephone invention had become the giant AT&T, which established its own laboratory (which eventually became known as Bell Labs); by 1915, it had developed amplifiers that made feasible nationwide long-distance telephone calls.[11] Successive inventions were then credited to the firm rather than to the

individual. Furthermore, a natural process of diminishing returns occurred in each industry. The number of patents issued in three industries that were new in the early twentieth century—the automobile, airplane, and radio—exhibit an initial explosion of patent activity followed by a plateau—or, in the case of automobiles after 1925, an absolute decline.[12] Richard Nelson describes this pattern as widespread:

> Following the breakthrough of a basic invention, there is at first a rising, then a falling, rate of increase in practical adoptions of the new invention. In time the new invention is made obsolete by still newer inventions, and its use declines or falls off entirely.[13]

Individual inventors flourished in the United States in part because of the democratic nature of the patenting system. From the beginning, the U.S. patent system was self-consciously designed to be different from European systems, "and nearly all of [the] alterations can be viewed as extending effective property rights in technological discoveries to classes of the population that would not have enjoyed them under traditional intellectual property institutions."[14] Detailed specifications of any patented invention were required to be made public immediately, and the patent fee was set at only 5 percent of the amount charged in Britain.[15] Patents solved the problem of theft of intellectual property in an environment in which inventors needed to learn about the latest inventions that might be complementary or perhaps a key ingredient in their own newest developments. In the United States, trade in patented technologies through licensing was much more extensive than in Europe, and as a result, "technologically creative people without the capital to go into business and directly exploit the fruits of their ingenuity were major beneficiaries."[16]

The low cost of patents fostered a unique aspect of American invention—that many of the inventors had only an elementary or secondary education. The patent system allowed them to develop their ideas without a large investment in obtaining a patent; once the patent was granted, even inventors who had a low personal income were able to attract capital funding and also to sell licenses. The U.S. patent system was revolutionary "in its extension of effective property rights in to an extremely wide spectrum of the population. Moreover, it was exceptional in recognizing that it was in the public interest that patent rights, like other property rights, should be clearly defined and well enforced, with low transaction costs."[17]

The democratic nature of the U.S. patent system may help to explain why so many of the Great Inventions of the late nineteenth century happened in the United States rather than in Europe. In a famous example discussed in chapter 6, on February 14, 1876, both Elisha Gray and Alexander Graham Bell arrived at the patent office to register their competing telephone technologies. Bell arrived a few hours earlier and became rich and famous, and Gray was forgotten. Years earlier, Antonio Meucci had developed his own version of the telephone but could not afford the patent application process in Italy.

Appearing to contradict the U-shaped evolution of innovation by individuals is the failure of the patent share of individuals to turn around after 1980. Instead, that share remains flat at 15 percent, down from 95 percent in 1880. This may be explained by the more rapid formation of corporations by individuals in the past three decades than in the late nineteenth century. Though the Harvard dropout Bill Gates may be said to have invented personal computer operating systems for the IBM personal computer, almost all Gates's patents were obtained after he formed the Microsoft corporation in 1975 (six years before IBM granted Microsoft the right to design and sell software for the earliest IBM PC). The same goes for the other individuals who developed Google's search software and Facebook's social network. Even though this wave of innovation is credited by the Patent Office to firms rather than individuals, it was made possible by individual inventors and entrepreneurs more directly than the earlier twentieth-century inventions of Bell Labs and the other large corporate research organizations.

THE HISTORICAL RECORD: THE GROWTH OF TOTAL FACTOR PRODUCTIVITY

We previously learned in figures 1–2 and 16–5 that growth in total factor productivity (TFP) was much faster between 1920 and 1970 than either before 1920 or since 1970. Now we take a closer look at the behavior of TFP growth for the years since 1970. Shown by vertical bars in figure 17–2 are the growth rates of TFP for 1890–1920, 1920–1970, and three subperiods since 1970. The first of these intervals, 1970–94, exhibits TFP growth of only 0.57 percent per year, less than a third of the 1.89 percent growth rate achieved in the fifty years before 1970. Then the two most recent decades between 1994 and 2014 are shown separately, with TFP growth notably faster in 1994–2004 than in the other two post-1970 intervals. Black is used to fill in the bars for the two

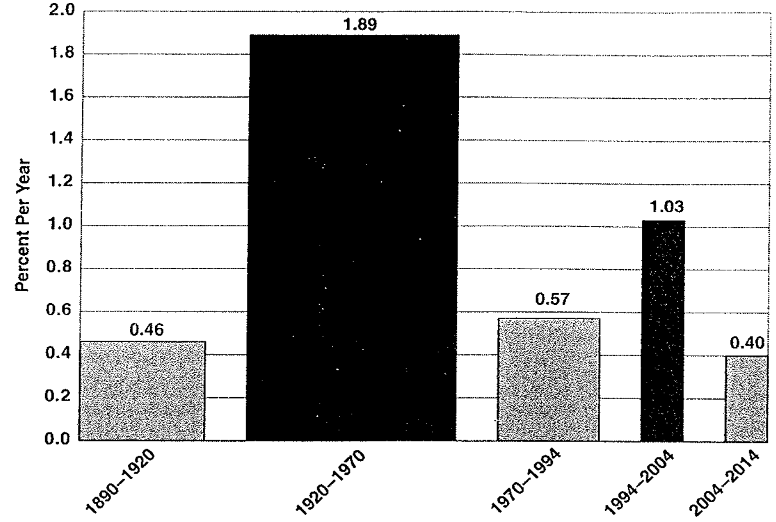

Figure 17–2. Annualized Growth Rates of Total Factor Productivity, 1890–2014

Source: Data underlying Figure 16–5.

periods with relatively rapid TFP growth—1920–70 and 1994–2004. Light gray is used to show the contrast with all the other intervals in which TFP growth is below 0.6 percent per year.

The contrast between the black and gray bars in figure 17–2 supports our interpretation that the great surge in the level of TFP was achieved primarily between 1920 and 1970 and was the result of the implementation and extension of many of the great inventions associated with the Second Industrial Revolution (IR #2) of the late nineteenth century. The brief revival of TFP growth in 1994–2004 reflects the contribution of the Third Industrial Revolution (IR #3) associated with computers and digitalization. Judged by their contributions to TFP growth, the two industrial revolutions were quite different—IR #2 created a great surge of TFP growth that lasted for a half century, while IR #3 caused a revival in TFP growth during 1994–2004 that was much shorter lived and smaller in magnitude.

The overwhelming dominance of the 1920–70 interval in making possible the modern world is clearly demonstrated. Though the great inventions of IR #2 mainly took place between 1870 and 1900, at first their effect was small. Paul David has provided a convincing case that almost four decades were required after Edison's first 1882 power station for the development of the machines and methods that finally allowed the electrified factory to emerge in the 1920s. Similarly, Karl Benz's invention of the first reliable internal combustion engine in 1879 was followed by two decades in which inventors experimented with brakes, transmissions, and other ancillary equipment needed to transfer the engine's power to axles and wheels. Even though the first automobiles appeared in 1897, they did not gain widespread acceptance until the price reductions made possible by Henry Ford's moving assembly line, introduced in 1913.

Why did the growth of TFP accelerate so rapidly after 1920, and why was the influence of IR#2 so profound? The saga of the roaring 1920s, followed by the dislocations of the Great Depression and World War II, disguises a rapid pace of innovation and implementation that started in the 1920s and took flight (both figuratively and literally) in the 1930s and 1940s, a story told in chapter 16. The digital revolution, IR #3, also had its main effect on TFP after a long delay. Even though the mainframe computer transformed many business practices starting in the 1960s, and the personal computer largely replaced the typewriter and calculator by the 1980s, the main effect of IR #3 on TFP was delayed until the 1994–2004 decade, when the invention of the Internet, web browsing, search engines, and e-commerce produced a pervasive change in every aspect of business practice.

Growth in output per person, our best measure of the rate of improvement in the standard of living, can proceed no faster than growth in output per hour unless hours worked per person exhibit an increase. Yet the ongoing retirement of the baby-boom generation, as we shall see in chapter 18, is already causing a decline in hours worked per person that is likely to continue for most of the next twenty-five years. Thus future growth in output per person will fall short of growth in output per hour, bringing labor productivity growth and its ultimate source, the pace of innovation as measured by TFP, to center stage in any discussion of the future of growth in American well-being. Accordingly, the chronology of figure 17–2 raises three important questions that will concern us throughout the rest of this chapter. First, why was the main effect of IR #3 on TFP so short-lived that its duration was limited to the 1994–2004 decade? Second, why was TFP growth so slow in the most recent 2004–14 decade? Third, what are the implications of slow recent TFP growth for the future evolution of TFP and labor productivity over the next quarter century?

ACHIEVEMENTS TO DATE OF THE THIRD INDUSTRIAL REVOLUTION

The third industrial revolution (IR #3) encompasses the digital age of information and communication technology (ICT), beginning with the first mainframe computers in the late 1950s and continuing until today and beyond. As we have seen, its main impact on TFP growth was limited to the 1994–2004 decade. It was driven by an unprecedented and never-repeated rate of decline in the price of computer speed and memory and a never-since-matched surge in the share of GDP devoted to investment in information and communication technology (ICT) investment.

The mediocre performance of TFP growth after 2004 underlines the temporary nature of the late 1990s revival. More puzzling is the absence of any apparent stimulus to TFP growth in the quarter-century between 1970 and 1994. Mainframe computers created bank statements and phone bills in the 1960s and powered airline reservation systems in the 1970s. Personal computers, ATMs, and barcode scanning were among the innovations that created productivity growth in the 1980s. Reacting to the failure of these innovations to boost productivity growth, Robert Solow quipped, "You can see the computer age everywhere but in the productivity statistics."[18] Slow TFP growth in this period indicates that the benefits of the first round of computer applications partially masked an even more severe slowdown in productivity growth than would have occurred otherwise in the rest of the economy.

The achievements of IR #3 can be divided into two major categories: communications and information technology. Within communications, progress started with the 1983 breakup of the Bell Telephone monopoly into non-overlapping regional monopolies. After a series of mergers, landline service was provided primarily by a new version of AT&T and by Verizon, soon to be joined by major cable television companies, such as Comcast and Time-Warner, that offered landline phone service as part of their cable TV and Internet packages.

The major advance in the communications sphere was the mobile phone, which made a quick transition from heavyweight bricklike models in the 1980s to the sleek small instruments capable by the late 1990s of phoning, messaging, e-mailing, and photography. The final communications revolution occurred in 2007 with the introduction by Apple of the iPhone, soon to be imitated by Google's Android operating system installed on phones manufactured mainly by foreign-owned companies such as Korea's Samsung. By 2015, there were 183 million smartphone users in the United States, or roughly sixty per

100 members of the population.[19] Though landline phone service was dominated by one or two providers in most metropolitan areas, landline phones were becoming increasingly irrelevant in the presence of smartphones; six companies competed vigorously to attract smartphone subscribers.

The "I" and the "T" of ICT began in the 1960s with the mainframe computer, which eliminated boring and routine clerical labor previously needed to prepare telephone bills, bank statements, and insurance policies. Credit cards would not have been possible without mainframe computers to keep track of the billions of transactions. Gradually electric memory typewriters and later personal computers eliminated repetitive retyping of everything from legal briefs to academic manuscripts. In the 1980s, three additional standalone electronic inventions introduced a new level of convenience into everyday life. The first of these was the ATM, which made personal contact with bank tellers unnecessary. In retailing, two devices greatly raised the productivity and speed of the checkout process: the barcode scanner and the authorization devices that read credit cards and within seconds denied or approved a transaction.

The late 1990s, when TFP growth finally revived, witnessed the marriage of computers and communication. Suddenly within the brief half-decade interval between 1993 and 1998, the standalone computer was linked to the outside world through the Internet, and by the end of the 1990s, web browsers, web surfing, and e-mail had become universal. The market for Internet services exploded, and by 2004, most of today's Internet giants had been founded. Throughout every sector, paper and typewriters were replaced by flat screens running powerful software. Professors no longer need to subscribe to or store academic journals. Instead they can access JSTOR, which has 8,000 subscribing institutions and provides full-text access to more than 2,000 journals.[20]

Although IR #3 was revolutionary, its effect was felt in a limited sphere of human activity, in contrast to IR #2, which changed everything. Categories of personal consumption expenditures that felt little effect from the ICT revolution were the purchase of food for consumption at home and away from home, clothing and footwear, motor vehicles and fuel to make them move, furniture, household supplies, and appliances. In 2014, fully two-thirds of consumption expenditures went for services, including rent, health care, education, and personal care. Barber and beauty shops were joined by tanning and nail salons, but the ICT revolution had virtually no effect. A pedicure is a pedicure regardless of whether the customer is reading a magazine (as would occur a decade ago) or reading a book on a Kindle or surfing the web on a smartphone.

This brings us back to Solow's quip—that we can see the computer age everywhere but in the productivity statistics. The final answer to Solow's computer paradox is that computers are not everywhere. We don't eat computers or wear them or drive to work in them or let them cut our hair. We live in dwelling units that have appliances much like those of the 1950s, and we drive in motor vehicles that perform the same functions as in the 1950s, albeit with more convenience and safety.

What are the implications of the uneven progress of TFP as shown in figure 17–2? Should the 0.40 percent growth rate of the most recent 2004–14 decade be considered the most relevant basis for future growth? Or should our projection for the future be partly or largely based on the 1.03 percent average TFP growth achieved by the decade 1994–2004? There are several reasons, beyond the temporary nature of the TFP growth recovery in 1994–2004, to regard those years as unique and not relevant for the next several decades.

COULD THE THIRD INDUSTRIAL REVOLUTION BE ALMOST OVER?

What factors caused the TFP growth revival of the late 1990s to be so temporary and to die out so quickly? Most of the economy has already benefited from the Internet and web revolution, and in this sphere of economic activity, methods of production have been little changed over the past decade. Across the economy, paper-dependent business procedures had by 2004 been replaced by digitalization, and flat screens were everywhere. The revolutions in everyday life made possible by e-commerce and search engines were already well established—Amazon dates back to 1994, Google to 1998, and Wikipedia as well as iTunes to 2001. Facebook, founded in 2004, is now more than a decade old. Will future innovations be sufficiently powerful and widespread to duplicate the relatively brief revival in productivity growth that occurred between 1994 and 2004?[21] Supporting the data showing that TFP growth was less than half as quick during 2004–14 as during 1994–2004 is the appearance that changes in business practices have been substantially slower within the most recent decade than during the prior decade.

A Slowing Transformation of Business Practices. The digital revolution centered on 1970–2000 utterly changed the way offices function. In 1970, the electronic calculator had just been introduced, but the computer terminal was still in the future. Office work required innumerable clerks to operate the keyboards of electric typewriters that had no ability to download content from the rest of the world and that, lacking a memory, required repetitive retyping of everything from legal briefs to academic research papers. Starting from this world of 1970, by 2000 every office was equipped with web-linked personal computers that not only could perform any word-processing task, but also could perform any type of calculation at blinding speed as well as download multiple varieties of content. By 2005, flat screens had completed the transition to the modern office, and broadband service had replaced dial-up service at home. But then progress slowed. Throughout the world, the equipment used in office work and the productivity of office employees closely resembles that of a decade ago.[22] And business productivity continues to enjoy the permanent increase in personal comfort on the job that was achieved between 1930 and 1970 by the introduction of air conditioning into every office setting.

A part of the great transition that was achieved in the 1980s and 1990s was the catalog revolution. Even before the web became pervasive in the late 1990s, libraries had already converted from wooden boxes of paper card catalogs to electronic catalogs that doubled not only as search tools but as inventory managers, indicating for every search result whether the book or periodical was on the shelf. The parts departments at automobile dealers made a transition at the same time to electronic catalogs from enormous binders into which multiple replacement pages had to be inserted every day. Hardware stores, book stores, garden nurseries, and, indeed, any retail store selling a large number of varieties of products shifted to electronic catalogs over proprietary computer networks even before the web allowed direct consumer contact with each merchant's catalog. The important point is that this transition from paper to electronic catalogs happened fifteen to twenty-five years ago and represented a one-time-only source of a jump in the *level* of productivity—hence a temporary rather than permanent increase in the *growth rate* of productivity.

In the past decade business practices, while relatively unchanged in the office, have steadily improved outside of the office as smartphones and tablets have become standard business equipment. A television service repair person arrives not with a paper work order and clipboard, but rather with a multipurpose smartphone. Product specifications and communication codes are available on the phone, and the customer completes the transaction by scrawling a signature on the phone screen. Paper has been replaced almost everywhere outside of the office. Airlines are well along in equipping pilots with smart tablets that contain all the information previously provided by large paper manuals. Maintenance crews at Exelon's six nuclear power stations in Illinois are the latest to be trading in their three-ring binders for iPads. The switch to tablets boosts productivity by eliminating not just the expense of the paper but also of photocopying and filing. "Interactivity, from email to downloads, means that maintenance workers can use tablets to get answers more quickly."[23]

A leading puzzle of the current age is why the near-ubiquity of smartphones and tablets has been accompanied by such slow economy-wide productivity growth, particularly since 2009. One answer is that smartphones are used in the office for personal activities. Some 90 percent of office workers, whether using their office personal computers or their smartphones, visit recreational web sites during the work day. Almost the same percentage admit that they send personal e-mails and more than half report shopping for personal purposes during work time. "Tracking software suggests that 70 percent of employees visit retail sites."[24]

Stasis in Retailing. Since the development of "big-box" retailers in the 1980s and 1990s, and the conversion of checkout aisles to barcode scanners, little has changed in the retail sector. Payment methods have gradually changed from cash and checks to credit and debit cards. In the early years of credit cards in the 1970s and 1980s, checkout clerks had to make voice phone calls for authorization, then there was a transition to terminals that would dial the authorization phone number, and now the authorization arrives within a few seconds. The big-box retailers brought with them many other aspects of the productivity revolution. Walmart and others transformed supply chains, wholesale distribution, inventory management, pricing, and product selection, but that productivity-enhancing shift away from traditional small-scale retailing is largely over. The retail productivity revolution is high on the list of the many accomplishments of IR #3 that are largely completed and will be difficult to surpass in the next several decades.

What is often forgotten is that we are well into the computer age, and many Home Depots and local supermarkets have self-checkout lines that allow customers to scan their groceries or paint cans through a standalone terminal. But except for small orders, doing so takes longer, and customers still voluntarily wait in line for a human instead of taking the option of the no-wait self-checkout lane. The same theme—that the most obvious uses of electronic devices have already happened—pervades commerce. Airport baggage sorting belts are mechanized, as is most of the process of checking in for a flight. But at least one human agent is still needed at each airline departure gate to deal with seating issues and stand-by passengers.

While the main impact on retail productivity growth of big-box stores and warehouse clubs had largely occurred by a decade ago, the past decade has witnessed the continued rapid growth of e-commerce that inherently operates at a higher level of labor productivity than brick-and-mortar retail stores. While nominal annual e-commerce sales grew 11-fold from 2000 to 2014, the share of e-commerce in all retail sales in 2014 was still only 6.4 percent, a fraction too small for e-commerce to have a major impact on productivity growth in the overall retail sector, much less in the economy as a whole (see Hortaçsu and Syverson, 2015, p. 7).

A Plateau of Activity in Finance and Banking. The ICT revolution changed finance and banking along many dimensions from the humble street-corner ATM to the development of fast trading on the stock exchanges. Both the ATM and billion-share trading days are creations of the 1980s and 1990s. Average daily shares transacted on the New York Stock Exchange increased from only 3.5 million in 1960 to 1.7 billion in 2005 and then declined to around 1.2 billion per day in early 2015. Figure 17–3 shows the average annual growth rate of shares transacted over five-year intervals, with the first bar referring to 1960–65 and the final (negative) bar displaying the growth rate for 2010–15.[25] Nothing much has changed in more than a decade, except for the ups and downs of stock prices, and despite all those ATMs—and a transition by many customers to managing their bank accounts online rather than by visiting bank

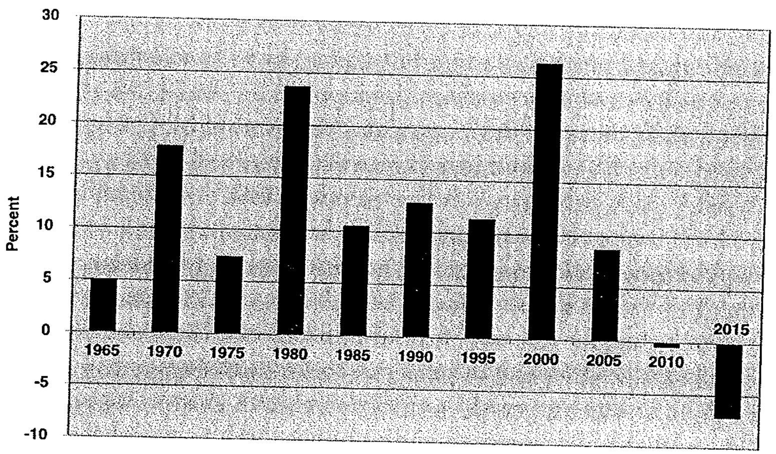

Figure 17–3. Average Annual Growth Rate of Daily Shares Traded on New York Stock Exchange, 1960–2015

Source: https://www.nyse.com/data/transactions-statistics-data-library. Each column reflects the annualized growth of the average volume traded in the first full week of each year.

branches—the nation still maintains a system of 97,000 bank branches, many of which are empty much of the time, and employment of bank tellers has declined only from 484,000 in 1985 to 361,000 recently.[26] James Bessen explains the longevity of bank branches in part by the effect of ATMs in reducing the number of employees needed per branch from about twenty in 1988 to a little more than thirteen in 2004. That meant it was less expensive for a bank to open a branch, leading banks to increase the number of bank branches by 43 percent over the same period between 1988 and 2004. This provides an example that the effect of robots, in this case ATMs, in causing a destruction of jobs is often greatly exaggerated. Bessen shows also that the invention of bookkeeping software did not prevent the number of accounting clerks from growing substantially between 1999 and 2009, although other evidence suggests that corporate financial software is continuing to reduce employment in corporate finance departments.[27]

The Home and Consumer Electronics. Each of the sectors discussed above (office work, retailing, finance, banking) went through fundamental and transformative changes in the 1980s and 1990s. Only within the past decade have computer hardware, software, and business methods ossified into a slowly changing set of routines. In contrast to the decade or so of stability in procedures at work, life inside the home has been stable not for a single decade, but for nearly a half-century. By the 1950s, all the major household appliances (washer, dryer, refrigerator, range, dishwasher, and garbage disposer) had been invented, and by the early 1970s, they had reached most American households. Besides the microwave oven, the most important change has been the comfort provided by air conditioning; by 2010, almost 70 percent of American dwelling units were equipped with central air conditioning.

Aside from air conditioning, the major changes in the home in the half century since 1965 were all in the categories of entertainment, communication, and information devices. Television made its transition to color between 1965 and 1972, then variety increased with cable television in the 1970s and 1980s, and finally picture quality was improved with high-definition signals and receiving sets. Variety increased even further when Blockbuster and then Netflix made it possible to rent an almost infinite variety of motion picture DVDs, and now movie streaming has become common. For the past decade, homes have had access to entertainment and information through fast broadband connections to the web, and smartphones have made the web portable. But now that smartphones and tablets have saturated their potential market, further advances in consumer electronics have become harder to achieve. The sense that technical change is slowing down in consumer electronic goods was palpable at the 2014 Consumer Electronics Show (CES):

> But in some ways, this show was a far cry from the shows of old.... [O]ver the years it has been the place to spot some real innovations. In 1970, the videocassette recorder was introduced at CES. In 1981 the compact disc player had its debut there. High definition TV was unveiled in 1998, the Microsoft Xbox in 2001. This year's crop of products seemed a bit underwhelming by comparison. The editor of...a gadget website [said] "this industry that employs all of these engineers, and has all of these factories and salespeople, needs you to throw out your old stuff and buy new stuff—even if that new stuff is only slightly upgraded."[28]

Decline in Business Dynamism. Recent research has used the word "dynamism" to describe the process of creative destruction by which new startups and young firms are the source of productivity gains that occur when they introduce best-practice technologies and methods as they shift resources away from old low-productivity firms. As shown in figure 17–4, the share of all business firms

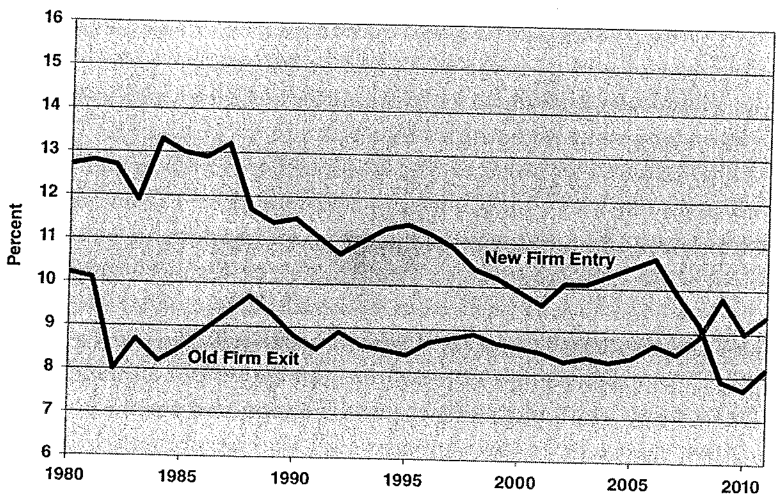

Figure 17–4. Rate of New Firm Entry and Old Firm Exit, 1980–2011
Source: Hathaway and Litan (2014).

consisting of young firms (aged five years or younger) declined from 14.6 percent in 1978 to only 8.3 percent in 2011 even as the share of firms exiting (going out of business) remained roughly constant in the range of 8–10 percent. It is notable that the share of young entering firms had already declined substantially before the 2008–9 financial crisis.[29] Measured another way, the share of total employment accounted for by firms no older than five years declined by almost half from 19.2 percent in 1982 to 10.7 percent in 2011. This decline was pervasive across retailing and services, and after 2000 the high-tech sector experienced a large decline in startups and fast-growing young firms.[30] In another measure of the decline in dynamism, the percentage of people younger than 30 who owned stakes in private companies declined from 10.6 percent in 1989 to 3.6 percent in 2014.[31]

Related research on labor market dynamics points to a decline in "fluidity" as job reallocation rates fell more than a quarter after 1990, and worker reallocation rates fell more than a quarter after 2000. Slower job and worker reallocation means that new job opportunities are less plentiful and it is harder to gain employment after long jobless spells. "For the employed it hampers their ability to switch employers so as to move up a job ladder, change careers, and satisfy locational constraints.... [J]ob mobility facilitates wage growth and career advancement."[32] This line of active current research has uncovered multiple dimensions of the declining "dynamism of American society" as indicated by the declining pace of startups, job creation, job destruction, and internal migration.[33]

OBJECTIVE MEASURES OF SLOWING ECONOMIC GROWTH

Thus far this section has provided two measures of a slowing pace of economic progress—the end of growth in stock market shares transacted and a sharp decline in business dynamism measured by the rate of entry of newly created business firms. These indicators coincide with the sharp decline in the growth of TFP that occurs when the most recent decade, 2004–14, is compared with the prior decade, 1994–2004. We now turn to additional objective measures that uniformly depict an economy that experienced a spurt of productivity and innovation in the 1994–2004 decade but that has slowed since then, in some cases to a crawl.

Manufacturing Capacity. The Federal Reserve reports monthly its Index of Industrial Production and Industrial Capacity, as well as the ratio of the two, the rate of capacity utilization. Shown in figure 17–5 is the annual growth rate of manufacturing capacity since 1980. The uniqueness of the 1994–2004 decade is evident, as the five-year growth rate of manufacturing capacity proceeded at

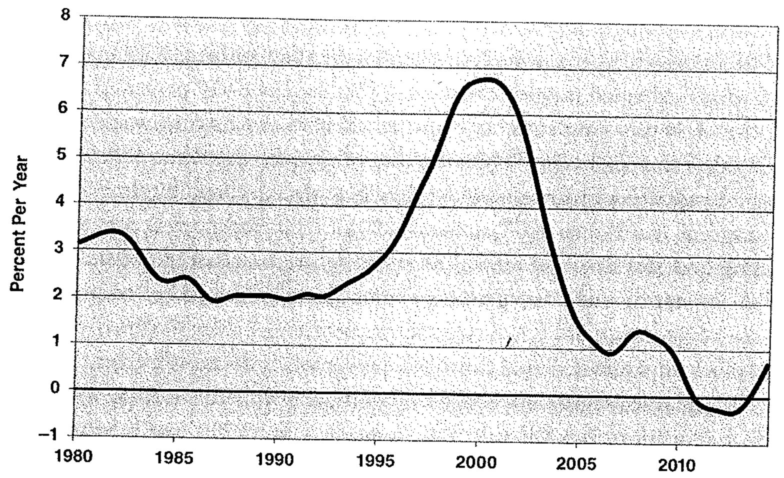

Figure 17–5. Quarterly Annualized Five-Year Change in Manufacturing Capacity, 1980–2014

Source: www.federalreserve.gov/datadownload/default.htm, G.17.

an annual rate between 2 percent and 3 percent from 1972 to 1994, surged to almost 7 percent in the late 1990s, and then came back down, reaching a negative growth rate in 2012. The role of ICT investment in temporarily driving up the growth rate of manufacturing capacity in the late 1990s is well known. Martin Baily and Barry Bosworth have emphasized that if ICT production is stripped out of the manufacturing data, TFP growth in manufacturing has been an unimpressive 0.3 percent per year between 1987 and 2011.[34] Daron Acemoglu and coauthors have also found that the impact of ICT on productivity disappears once the ICT-producing industries are excluded; their finding is that for the remaining industries there is no tendency for labor productivity to grow faster in industries that are "ICT-intensive"—that is, that have a relatively high ratio of expenditures on computer equipment to their expenditures on total capital equipment.[35]

Net Investment. The second reason that the productivity revival of the late 1990s is unlikely to be repeated anytime soon is the behavior of net investment. As shown in figure 17–6, the ratio of net investment to the capital stock (shown as a five-year moving average) has been trending down since the 1960s relative to its 1950–2007 average value of 3.2 percent. In fact, during the entire period 1986–2013, the ratio exceeded that 3.2 percent average value for

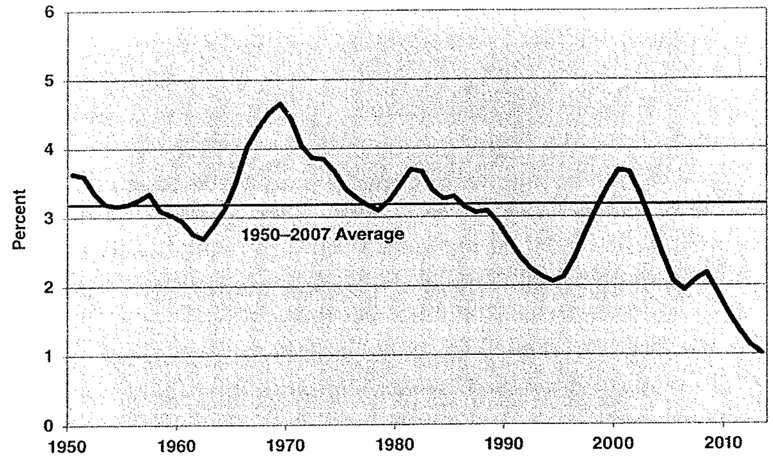

Figure 17–6. Five-Year Moving Average of Ratio of Net Private Business Investment to Private Business Capital Stock, 1950–2013

Sources: BEA Fixed Assets Accounts, Tables 4.1, 4.4, and 4.7.

only four years, 1999–2002, that was within the interval of the productivity growth revival. The 1.0 percent value of the moving average in 2013 was less than half of the previous value in 1994 and less than a third of the 3.2 percent 1950–2007 average. Thus the investment needed to support a repeat of the late 1990s productivity revival has been missing during the past decade.

Computer Performance. Another piece of evidence that the late 1990s were unique refers to the rate of improvement in computer performance. The 1996–2000 interval witnessed the most rapid rate of decline in performance-adjusted prices of ICT equipment recorded to date. The quicker the rate of decline in the ICT equipment deflator, the more quickly the price of computers is declining relative to their performance, or the more quickly computer performance is increasing relative to its price. As shown in the top frame of figure 17–7, the rate of decline of the ICT equipment deflator peaked at −14 percent in 1999 but then steadily diminished to barely minus 1 percent in 2010–14. The slowing rate of improvement of ICT equipment has been reflected in a sharp slowdown in the contribution of ICT as a factor of production to growth in labor productivity. The latest estimates of the ICT contribution by Gilbert Cette and coauthors declines from 0.52 percentage points per year during 1995–2004 to 0.19 points per year during 2004–2013.[36]

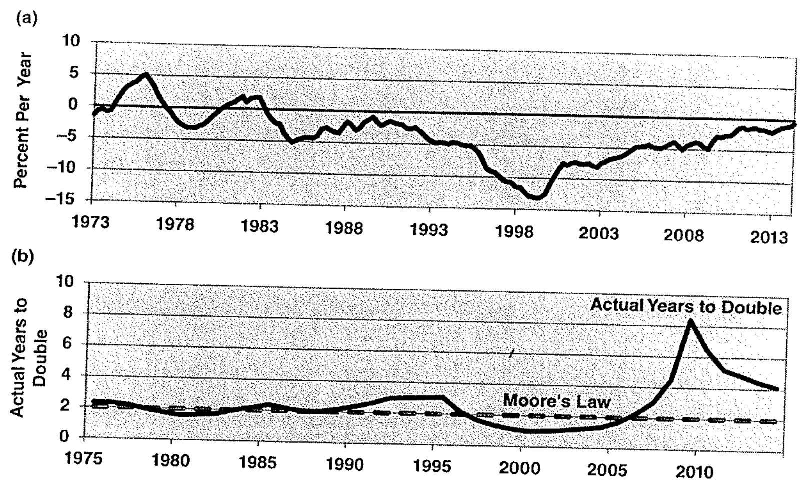

Figure 17–7. a. Annual Change of Price Index for Information and Communication Technology, 1973–2014. b. Years Taken for Number of Transistors on a Chip to Double, 1975–2014

Source: (a) NIPA Table 5.3.4. (b) Data underlying Figure 13–1.

Moore's Law. We learned in chapter 13 that the late 1990s were not only a period of rapid decline in the prices of computer power, but also simultaneously a period of rapid change in the progress of computer chip technology. Moore's Law was originally formulated in 1965 as a forecast that the number of transistors on a computer chip would double every two years. The horizontal dashed line in the bottom frame of figure 17–7 at a vertical distance of two years represents the prediction of Moore's Law. The black line plots the actual doubling time, which followed the predicted value of almost exactly two years with uncanny accuracy between 1975 and 1990. Then the doubling time crept up to three years during 1992–96, followed by a plunge to less than eighteen months between 1999 and 2003. Indeed, the acceleration of technical progress in chip technology in the bottom frame of figure 17–7 was the underlying cause of the rapid decline in the ratio of price-to-performance for computer equipment shown in the top frame. The doubling time reached a trough of fourteen months in 2000, roughly the same time as the peak rate of decline in the computer deflator. But since 2006, Moore's Law has gone off the rails: The doubling time soared to eight years in 2009 and then declined gradually to four years in 2014.

Kenneth Flamm examines the transition over the past decade toward a substantially slower rate of improvement in computer chips and in the quality-corrected performance of computers themselves. His data show that the "clock speed," a measure of computer performance, has been on a plateau of no change at all since 2003, despite a continuing increase in the number of transistors squeezed onto computer chips. He concludes:

> The weight of empirical evidence developed and reviewed in this paper suggests that since 2003, there have been notable reductions in both the rate of price decline, and in the pace of technical innovation, in the semiconductor manufacturing industry generally, and the microprocessor manufacturing industry in particular. . . . [T]here will be a significant and widely felt economic downside to a reduction in the rate of innovation in semiconductor manufacturing. A slackening of declines in IT hardware prices will, through the same causal links, reduce productivity growth across the broad economy relative to what it would have been had the faster pace of innovation continued.[37]

These four factors unique to the late 1990s—the surge in manufacturing capacity, the rise in the net investment ratio, the trough in the rate of decline in computer prices with the associated decline in the contribution of ICT capital to labor productivity growth, and the shift in the timing of Moore's Law—all create a strong case that the dot-com era of the late 1990s was unique in its conjunction of factors that boosted growth in labor productivity and of TFP well above both the rate achieved during 1970–94 and during 2004–14. There are no signs in recent data that anything like the dot-com era is about to recur—manufacturing capacity growth turned negative during 2011–12 and the net investment ratio fell during 2009–13 to barely a third of its postwar average.

CAN FUTURE INNOVATION BE PREDICTED?

What is in store for the next twenty-five years? Will technological change accelerate and push TFP well above its rate of the past forty years? Or does the slow TFP growth achieved in the most recent 2004–14 decade indicate that the dot-com revolution of the prior 1994–2004 decade was sui generis, an accomplishment unlikely to be repeated? Before speculating about the future, we need to ask whether any such attempt at forecasting is feasible.

The usual stance of economic historians, including my colleague Joel Mokyr, is that the human brain is incapable of forecasting future innovations. He states without qualification that "History is always a bad guide to the future and economic historians should avoid making predictions."[38] He assumes that an instrument is necessary for an outcome. As an example, it would have been impossible for Pasteur to discover his germ theory of disease if Joseph A. Lister had not invented the achromatic-lens microscope in the 1820s. Mokyr's optimism about future technological progress rests partly on the dazzling array of new tools that have arrived recently to create further research advances—"DNA sequencing machines and cell analysis," "high-powered computers," and "astronomy, nanochemistry, and genetic engineering." One of Mokyr's central tools in facilitating scientific advance is "blindingly fast search tools" so that all of human knowledge is instantly available.

Mokyr's examples of future progress do not center on digitalization but rather involve fighting infectious diseases, the need of technology to help reduce the environmental pollution caused by excess fertilizer use, and the evocative query, "Can new technology stop [global warming]?" It is notable that innovations to fight pollution and global warming involve fighting "bads" rather than creating "goods." Instead of raising the standard of living in the same manner as the past two centuries of innovations that have brought a wonder of new goods and services for consumers, innovations to stem the consequences of pollution and global warming seek to prevent the standard of living from declining.

Mokyr and other historians scoff at any attempt to forecast the future; any pessimist gazing into the future is condemned for a lack of imagination and doomed to repeat the mistakes of past pessimists. But the common assumption that future innovation is non-forecastable is wrong. There are historical precedents of correct predictions made as long as fifty or 100 years in advance. After we review some of these, we will return to today's forecasts for the next quarter-century.

An early forecast of the future of technology is contained in Jules Verne's 1863 manuscript *Paris in the Twentieth Century,* in which Verne made bold predictions about the Paris a century later in 1960.[39] In that early year, before Edison or Benz, Verne had already conceived of the basics of the twentieth century. He predicted rapid transit cars running on overhead viaducts, motor cars with gas combustion engines, and street lights connected by underground wires. In fact, much of IR #2 was not a surprise. Looking ahead in the year 1875, inventors were feverishly working on turning the telegraph into the telephone, trying to find a way to transform electricity coming from batteries into electric light, trying to find a way of harnessing the power of petroleum to create a lightweight and powerful internal combustion engine. The atmosphere of 1875 was suffused with "we're almost there" speculation. After the relatively lightweight internal combustion engine was achieved, flight, humankind's dream since Icarus, became a matter of time and experimentation.[40] Some of the most important sources of human progress over the 1870–1940 period were not new inventions at all. Running water had been achieved by the Romans, but it took political will and financial investment to bring it to every urban dwelling place. A separate system of sewer pipes was not an invention, but implementing it over the interval 1870–1930 required resources, dedication, and a commitment to using public funds for infrastructure investment.

A set of remarkable forecasts appeared in December 1900 in an unlikely publication medium—the *Ladies Home Journal.* Some of the predictions were laughably wrong and unimportant, such as strawberries the size of baseballs. But there were enough accurate predictions in this page-long three-column article to suggest that much of the future can be known.[41] Some of the more interesting forecasts follow:

- "Hot and cold air will be turned on from spigots to regulate the temperature of the air just as we now turn on hot and cold water from spigots to regulate the temperature of the bath."
- "Ready-cooked meals will be purchased from establishments much like our bakeries of today."
- "Liquid-air refrigerators will keep large quantities of food fresh for long intervals."
- "Photographs will be telegraphed from any distance. If there is a battle in China a century hence, photographs of the events will be published in newspapers an hour later."
- "Automobiles will be cheaper than horses are today. Farmers will own automobile hay-wagons, automobile truck-wagons...automobiles will have been substituted for every horse-vehicle now known."
- "Persons and things of all types will be brought within focus of cameras connected with screens at opposite ends of circuits, thousands of miles at a span.... [T]he lips of a remote actor or singer will be heard to offer words or music when seen to move."

The Jules Verne 1863 and the *Ladies Home Journal* 1900 visions of future technological progress were true leaps of imagination. Somewhat less challenging were predictions of the future made at the 1939–40 New York World's Fair. By then, IR #2 was almost complete in urban America, so it is no surprise that the exhibits at the fair could predict quite accurately the further complements to IR #2 inventions, such as superhighways. A future of air-conditioned homes and businesses was no intellectual stretch at the fair, for air conditioning in movie theaters began in 1922 and was nearly ubiquitous in theaters and new office buildings by the late 1930s. Television was introduced at the fair, and it was easy to predict then that television over the next two decades would follow the American model of commercially supported radio, with entertainment provided over several large networks spanning the continent. Although commercial aviation was primitive in 1939, still it was easy to forecast from the rapid progress in the size and speed of aircraft over the 1920–40 period that much larger aircraft could fly much longer distances, and indeed within only a few years the DC-6 and DC-7 were spanning the continent and the globe before the epochal introduction of the Boeing 707 jet in 1958.

What was missing at the 1939–40 World's Fair was any vision of the computer revolution that created IR #3. But Norbert Wiener, a visionary, in a 1949 essay that was ultimately rejected by the *New York Times*, got a lot of the future of IR #3 right. Among his 1949 predictions were these:

> These new machines have a great capacity for upsetting the present basis of industry, and of reducing the economic value of the routine factory employee to a point at which he is not worth hiring at any price.... [I]f we move in the direction of making machines which learn and whose behavior is modified by experience, we must face the fact that every degree of independence we give the machine is a degree of possible defiance of our wishes. The genie in the bottle will not willingly go back in the bottle, nor have we any reason to expect them to be well-disposed to us.[42]

Just as some inventions have come as a surprise, including the entire electronics and digital revolutions, other anticipated inventions never came to pass. Dick Tracy's wrist radio in cartoon comic strips of the late 1940s finally is coming to fruition seventy years later with the Apple Watch. The Jetsons' vertical

commuting car/plane never happened, and in fact high fuel costs caused many local helicopter short-haul aviation companies to shut down.[43] As Peter Theil quipped, "We wanted flying cars, instead we got 140 characters."

THE INVENTIONS THAT ARE NOW FORECASTABLE

Despite the slow growth of TFP recorded by the data of the decade since 2004, commentators view the future of technology with great excitement. Nouriel Roubini writes, "[T]here is a new perception of the role of technology. Innovators and tech CEOs both seem positively giddy with optimism."[44] The well-known pair of techno-optimists Erik Brynjolfsson and Andrew McAfee assert that "we're at an inflection point" between a past of slow technological change and a future of rapid change.[45] They appear to believe that Big Blue's chess victory and Watson's victory on the TV game show *Jeopardy* presage an age in which computers outsmart humans in every aspect of human work effort. They remind us that Moore's Law predicts endless exponential growth of the performance capability of computer chips—but they ignore that chips have fallen behind the predicted pace of Moore's Law after 2005. The decline in the price of ICT equipment relative to performance was most rapid in the late 1990s, and there has been hardly any decline at all in the past few years. Exponential increases in computer performance will continue, but at a slower rate than in the past, not at a faster rate (see figure 17–7).

The theme of this chapter is that the main benefits for productivity growth provided by the digital Third Industrial Revolution were centered on the decade between 1994 and 2004. Since 2004, the pace of innovation has been slower, but certainly it has not been zero. The new portability of the web made possible by smartphones and tablets has continued to change business practices and consumer well-being. When we examine the likely innovations of the next several decades, we are not doubting that many innovations will continue to occur but rather are assessing them in the context of the past two decades of fast (1994–2004) and then slow (2004–14) growth in TFP. Will the next wave of innovations change business practices in a revolutionary way, as did the dot-com revolution of the late 1990s, or will innovation cause productivity to increase at an evolutionary pace, like that of the most recent decade?

The future advances that are widely forecast by Brynjolfsson, McAfee, and others can be divided into four main categories—medical, small robots and 3D printing, big data, and driverless vehicles. Enthusiasts of "big data" sometimes label this category of advance as "artificial intelligence." It is worth examining the potential of each of these categories of future innovation in turn to create a boost in TFP growth back to the level achieved in the late 1990s.

Medical and Pharmaceutical Advances. The most important sources of longer life expectancy in the twentieth century were achieved in the first half of that century, when life expectancy rose at twice the rate it did in the last half. This was the interval when infant mortality was conquered and life expectancy was extended by the discovery of the germ theory of disease, the development of an antitoxin for diphtheria, and the near elimination of contamination of milk and meat as well as the conquest of air- and water-distributed diseases through the construction of urban sanitation infrastructure.[46] Many of the current basic tools of modern medicine were developed between 1940 and 1980, including antibiotics, the polio vaccine, procedures to treat coronary heart disease, and the basic tools of chemotherapy and radiation to treat cancer, all advances that contribute to productivity growth.

Medical technology has not ceased to advance since 1980 but rather has continued at a slow and measured pace, and life expectancy has continued to improve at a steady rate (as shown in figure 7–2), while the mortality rate for cardiac-related diseases has steadily declined. It is likely that life expectancy will continue to improve at a rate not unlike that of the past few decades. There are new issues, however. As described by Jan Vijg, an eminent geneticist, progress on physical disease and ailments is advancing faster than on mental disease, which has led to widespread concern that in the future there will be a steady rise in the burden of taking care of elderly Americans who are alive but in a state of dementia.

Pharmaceutical research has reached a brick wall of rapidly increasing costs and declining benefits, with a decline in major drugs approved each pair of years over the past decade, as documented by Vijg. At enormous cost, drugs are being developed that will treat esoteric types of cancer at costs that no medical insurance system can afford. Vijg is highly critical of the current regime of drug testing in the United States as inhibiting risk taking, an example of the overregulation of the U.S. economy.[47] The upshot is that over the next few decades, medical and pharmaceutical advances will doubtless continue, while the increasing burden of Alzheimer's care will be a significant contributor to increased cost of the medical care system.

Small Robots and 3D Printing. Industrial robots were introduced by General Motors in 1961. By the mid-1990s, robots were welding automobile parts and replacing workers in the lung-killing environment of the automotive paint shop.[48] Until recently, however, robots were large and expensive and needed to be "caged off to keep them from smashing into humans." The ongoing reduction in the cost of computer components has made feasible ever smaller and increasingly capable robots. Gill Pratt enumerates eight "technical drivers" that are advancing at steady exponential rates. Among those relevant to the development of more capable robots are exponential growth in computer performance, improvements in electromechanical design tools, and improvements in electrical energy storage. Others on his list involve more general capabilities of all digital devices, including exponential expansion of local wireless communications, in the scale and performance of the Internet, and in data storage.[49]

As an example of the effects of these increasing technical capabilities, inexpensive robots suitable for use by small businesses have been developed and brought to public attention by a 2012 segment on the TV program *60 Minutes* featuring Baxter, a $25,000 robot. The appeal of Baxter is that the cost is so cheap and that it can be reprogrammed to do a different task every day. Other small robots are mobile and can move around the factory floor. Often the robots work with humans rather than replacing them.[50] These small robots are no different in principle from the introduction of machinery dating back to the textile looms and spindles of the early British industrial revolution. Most workplace technologies are introduced with the intention of substituting machines for workers. Because this has been going on for two centuries, why are there then still so many jobs? Why in mid-2015 was the U.S. unemployment rate close to 5 percent instead of 20 or 50 percent?

David Autor has posed this question as well as answered it: Machines, including futuristic robots, not only substitute for labor, but also complement labor:

> Most work processes draw upon a multifaceted set of inputs: labor and capital; brains and brawn; creativity and rote repetition; technical mastery and intuitive judgment; perspiration and inspiration; adherence to rules and judicious application of discretion. Typically, these inputs *each* play essential roles; that is, improvements in one do not obviate the need for the other.[51]

Just as Baxter cooperates with human workers, other robots do not just displace workers but also make the remaining workers more valuable and create new jobs, including those who are building and programming the robots.

The complementarity between robots and human workers is illustrated by the cooperative work ritual taking place daily in Amazon warehouses, often cited as a frontier example of robotic technology. Far from replacing all human workers, in these warehouses the Kiva robots do not actually touch any of the merchandise but rather are limited to lifting shelves containing the objects and moving the shelves to the packer, who lifts the object off the shelf and performs the packing operation by hand.[52] The tactile skills needed for the robots to distinguish the different shapes, sizes, and textures of the objects on the shelves are beyond the capability of current robot technology. Other examples of complementarities include ATMs, which, as already noted, have been accompanied by an increase, rather than a decrease, in the number of bank branches, and the barcode retail scanner, which works along with the checkout clerk without replacing these employees, with little traction thus far for self-checkout lanes.

The exponential increase in computer speed and memory has apparently raced far ahead of the capability of robots to duplicate human movements. Though Google is experimenting with robots shaped like wild animals that can run at great speeds, so far robots are having great difficulty simply standing up. The recent finals of a three-year competition in which research teams developed the latest robots, "saw robots fall every which way. They fell on their faces. They fell on their backs. They toppled like toddlers, they folded like cheap suits, they went down like tonnes of bricks."[53]

Daniela Rus, Director of MIT's Computer Science and Artificial Intelligence Laboratory, provides a summary of some of the limitations of the robots developed to date. Robotic reasoning is limited, and "the scope of the robot's reasoning is entirely contained in the program.... Tasks that humans take for granted—for example, answering the question, 'Have I been here before?'—are extremely difficult for robots." Further, if a robot encounters a situation that it has not been specifically programmed to handle, "it enters an error state and stops operating."[54] Surely multiple-function robots will be developed, but it will be a long and gradual process before robots outside of the manufacturing and wholesaling sectors become a significant factor in replacing human jobs in the service, transportation, or construction sectors. And it is in those sectors that the slowness of productivity growth is a problem. For instance, consider the task of folding laundry, which is simple and routine for humans no matter their level of education:

> No machine can yet match a human's dexterity and problem-solving abilities when attacking a pile of irregular shaped clothes of different fabric types and weight. The difference between picking up a lace nightgown versus unraveling a pair of crumpled jeans knotted with other clothes is a calculation that requires massive computing power and a soft touch.[55]

3D printing is another revolution described by the techno-optimists. Its most important advantage is the potential to speed up the design process of new products. New prototypes can be designed in days or even hours rather than months and can be created at relatively low cost, lowering one major barrier to entry for entrepreneurs trying to attract financing for their startups. New design models can be simultaneously produced at multiple locations around the world. 3D printing also excels at one-off customized operations, such as the ability to create a crown in a dentist office instead of having to send out a mold, reducing the process of creating and installing a dental crown from two office visits to one. Thus it may contribute to productivity growth by reducing certain inefficiencies and lowering barriers to entrepreneurship, but these are unlikely to be huge effects felt throughout the economy. 3D printing is not expected to have much effect on mass production and thus on how most U.S. consumer goods are produced.

Big Data and Artificial Intelligence. The core of the optimists' case lies not with physical robots or 3D printing but with the growing sophistication and humanlike abilities of computers that are often described as "artificial intelligence." Brynjolfsson and McAfee provide many examples to demonstrate that computers are becoming sufficiently intelligent to supplant a growing share of human jobs. "They wonder if automation technology is near a tipping point, when machines finally master traits that have kept human workers irreplaceable."[56]

Thus far, it appears that the vast majority of big data is being analyzed within large corporations for marketing purposes. The *Economist* reported recently that corporate IT expenditures for marketing purposes were increasing at three times the rate of other corporate IT expenditures. The marketing wizards use big data to figure out what their customers buy, why they change their purchases from one category to another, and why they move from merchant to merchant. With enough big data, Corporation A may be able to devise a strategy to steal market share from Corporation B, but B will surely fight back with an onslaught of more big data. An excellent current example involves the large legacy airlines with their data-rich frequent flyer programs. The analysts at these airlines are constantly trolling through their big data trying to understand why they have lost market share in a particular city or with a particular demographic group of travelers.

Every airline has a "revenue management" department that decides how many seats on a given flight on a given day should be sold at cheap, intermediate, and expensive prices. Vast amounts of data are analyzed, and computers examine historical records, monitor day-by-day booking patterns, factor in holidays and weekends, and come out with an allocation. But at a medium-sized airline, JetBlue, twenty-five employees are required to monitor computers, and the humans must constantly override the computers' decisions. The director of revenue management at JetBlue describes his biggest surprise since taking over his job as "how often the staff has to override the computers."[57] Another example of the use of artificial intelligence is in apparel retailing. "At Macy's, for instance, algorithmic technology is helping fuse the online and the in-store experience, enabling a shopper to compare clothes online, try something on at the store, order it online, and return it in person. Algorithms . . . let companies target offers to specific consumers while they are shopping in stores."[58]

Marketing is just one form of artificial intelligence that has been made possible by big data. Computers are working in fields such as medical diagnosis, crime prevention, and loan approvals. In some cases, human analysts are replaced, but often the computers speed up a process and make it more accurate, working alongside human workers. New software allows consumer lending officers to "know borrowers as never before, and more accurately predict whether they will repay."[59] Vanguard and Charles Schwab have begun to compete with high-priced human financial advisers by offering "robo-advisers," online services that offer automated investment management via software. They use computer algorithms to choose assets consistent with the client's desired allocation at a cost that is a mere fraction of the fees of traditional human advisers. Thus far, robo-advisers mainly appeal to young people who have not yet built up much wealth; this application of artificial intelligence has not yet made much of a dent in advising high-net-worth individuals. It has been estimated recently that the combined assets under management by robo-advisers still amounts to less than $20 billion, against $17 trillion for traditional human advisers.[60]

Another use of artificial intelligence is now almost two decades old: the ability to use modern search tools to find with blinding speed valuable nuggets of existing information. The demand for legal associates has declined in part because of the ability of computerized search tools to carry out the process of discovery and search for precedents. "Computers are reading millions of documents and sorting them for relevance without getting tired or distracted. . . . As such analytical power expands in scope, computers will move nearer to the heart of what lawyers do by advising better than lawyers can on whether to sue or settle or go to trial."[61]

These examples of advanced search technology and artificial intelligence indeed are happening now, but they are nothing new. The quantity of electronic data has been rising exponentially for decades without pushing TFP growth out of its post-1970 lethargy, except for the temporary productivity revival period of 1994–2004. The sharp slowdown in productivity growth in recent years has overlapped with the introduction of smartphones and iPads, which consume huge amounts of data. These sources of innovation have disappointed in what counts in the statistics on productivity growth, their ability to boost output per hour in the American economy. As shown in figure 17–2, there has been no response at all of TFP growth to the 2007 introduction of the smartphone or the 2010 introduction of the smart tablet.[62]

Driverless Cars. This category of future progress is demoted to last place because it offers benefits that are minor compared to the invention of the car itself or the improvements in safety that have created a tenfold improvement in fatalities per vehicle mile since 1950. The most important distinction is between cars and trucks. People are in cars to go from A to B, much of it for essential aspects of life such as commuting or shopping. Thus the people must be inside the driverless car to achieve their objective of getting from point A to point B. The additions to consumer surplus of being able to commute without driving are relatively minor. Instead of listening to the current panoply of options, including Bluetooth phone calls, radio news, or Internet-provided music, drivers will be able to look at a computer screen or their smartphones, read a book, or keep up with their e-mail. The use of driverless cars is predicted to reduce the incidence of automobile accidents, continuing the steady decline in automobile accidents and fatalities that has already occurred. Driverless car technology may also help to foster a shift from nearly universal car ownership to widespread car sharing in cities and perhaps suburbs, leading to reductions in gasoline consumption, air pollution, and the amount of land devoted to parking, all of which should have positive effects on quality of life if not on productivity growth.

That leaves the potential future productivity advantage offered by driverless trucks. This is a potentially productivity-enhancing innovation, albeit within the small slice of U.S. employment consisting of truck drivers. However, driving from place to place is only half of what many truck drivers do. Those driving Coca-Cola and bread delivery trucks do not just stop at the back loading dock and wait for a store employee to unload the truck. Instead, the drivers are responsible for loading the cases of Coca-Cola or the stacks of bread loaves onto dollies and placing them manually on the store shelves. In fact, it is remarkable in this late phase of the computer revolution that almost all placement of individual product cans, bottles, and tubes on retail shelves is achieved today by humans rather than robots. Driverless delivery trucks will not save labor unless work is reorganized so that unloading and placement of goods from the driverless trucks is taken over by workers at the destination location.

The enthusiasm of techno-optimists for driverless cars leaves numerous issues unanswered. As pointed out by Autor, the experimental Google car "does not drive on roads" but rather proceeds by comparing data from its sensors with "painstakingly hand-curated maps." Any deviation of the actual environment from the pre-processed maps, such as a road detour or a crossing guard in place of the expected traffic signal, causes the driving software to blank out and requires instant resumption of control by the human driver.[63] At present, tests of driverless cars are being carried out on multilane highways, but test models so far are unable to judge when it is safe to pass on a two-lane road or to navigate winding rural roads in the dark. In the words of computer expert Rus:

> So far, that level of autonomous driving performance has been possible only in low-speed, low-complexity environments. Robotic vehicles cannot yet handle all the complexities of driving "in the wild," such as inclement weather and complex traffic situations. These issues are the focus of ongoing research.[64]

A future of driverless cars and trucks raises issues of legal liability that are now just beginning to be considered. Nonetheless, both Google and Tesla have announced plans to introduce certain aspects of driverless car technology in the near future, first as a type of highway autopilot not too far removed from the older technology of cruise control. Perfection in electronic devices is still years away, as has been demonstrated by defects in voice-activated computer controls:

> Voice-activated command systems and their software often are badly outdated or unreliable, leading to a tide of customer complaints and research questioning how safe they really are.... Voice control can be extremely buggy and the struggle to get them to work can cause a driver to miss traffic hazards.... *Consumer Reports* magazine found that problems with infotainment systems—music players, navigation and hands-free systems linking smartphones—are now the No. 1 reason for complaints.[65]

CONCLUSION

The title of this chapter asks, "Can the future match the great inventions of the past?" The criterion for "match" refers to the standard economic measure of the impact of innovation and technological change, that is, the growth rate of total factor productivity (TFP). Innovation is judged to have a high impact when TFP growth is relatively fast and to have a low impact when TFP growth is relatively slow. This standard of comparison across eras creates a distinction between the *pace* of innovation and the *impact* of innovation on TFP. We contrast the hyperactive pace of innovation at the current time (with multi-billion-dollar initial public offerings of tech-related new companies almost every week) with its apparently weak impact, judging by the slow pace of TFP growth exhibited in the data for the past decade.

This book has interpreted the ups and downs of TFP growth since the late nineteenth century as the result of successive industrial revolutions. The most remarkable fact about TFP performance is that rapid growth was not spread out evenly over the twelve-plus decades since 1890 but rather was concentrated in the middle of the twentieth century, with an average annual rate of TFP growth of 1.89 percent per year between 1920 and 1970. In 1970–2014, by contrast, the growth rate was only 0.64 percent per year, just a third the pace of 1920–70.

This chapter argues that the 1920–70 upsurge in TFP growth reflected the importance of the great inventions of the Second Industrial Revolution (IR #2). Our interpretation is that the digital Third Industrial Revolution (IR #3), though utterly changing the way Americans obtain information and communicate, did not extend across the full span of human life as did IR #2, with the epochal changes it created in the dimensions of food, clothing, housing and its equipment, transportation, information, communication, entertainment, the curing of diseases and conquest of infant mortality, and the improvement of working conditions on the job and at home. The surge of TFP growth during 1920–70 culminated with three offshoots of IR #2 that reached their current form forty years or more ago, with only minor changes since: highway travel via the interstate highway system, jet commercial air travel, and ubiquitous air conditioning.

The focal point of impact for IR #3 came in the decade 1994–2004, when TFP grew at a rate of 1.03 percent per year, little better than half that of 1920–70 but substantially faster than the rates of 0.57 percent per year for 1970–1994 and 0.40 for 2004–14. In our interpretation, there was a one-time-only revolution in business practices that coincided with the marriage between personal computers and communication that occurred when Internet browsers were introduced in the mid-1990s. Offices made the transition from piles of paper and filing cabinets to flat screens and cloud storage. Paper library card catalogs and parts lists made their transition to searchable video screens. TFP growth responded, but when by 2004, the main elements of the web-enabled transition had taken place, the *level* of TFP had achieved a higher plateau, and the *growth rate* of TFP then slowed appreciably.

No one can foresee the future, but we can ask whether the future is more likely to resemble the dot-com decade of 1994–2004 or the most recent decade, 2004–14. This chapter has assembled two types of evidence that the more rapid growth of TFP during 1994–2004 represented a temporary upsurge that is unlikely to be repeated. Descriptive assessments judge the pace of change in business practices, whether in the office, the retail store, or financial markets, to have slowed markedly after the rapid transition to modern methods achieved during the 1994–2004 decade. Six types of objective measures all show a peak of activity during the late 1990s and a sharp slowdown, stasis, or even decline in the most recent decade. These include the number of daily transactions on the New York Stock Exchange, the rate of creation of new business firms, the growth of manufacturing capacity, the rate of net investment, the rate of improvement in the performance of computer equipment relative to its price, and the rate of improvement of the density of computer chips.

The chapter calls attention to an apparent conflict between the excitement of techno-optimists regarding the newly enhanced capacity of artificial intelligence to mimic and surpass human activity, versus the slow ongoing growth of TFP over the past decade. One resolution is that the replacement of human jobs by computers has been going on for more than five decades, and the replacement of human jobs by machines in general has been going on for more than two centuries. Occupations such as financial advisers, credit analysts, insurance agents, and others are in the process of being replaced, and these displaced workers

follow in the footsteps of victims of the web who lost their jobs within the past two decades, including travel agents, encyclopedia salesmen, and employees of Borders and Blockbuster. Yet these previous job losses did not prevent the U.S. unemployment rate from declining to a rate near 5 percent in 2015, because new jobs were created to replace the jobs that were lost.

Most of us in our daily life encounter many different types of employees, and we can play a game I call "find the robot." Besides the ATM, the other robot I occasionally encounter is the automated e-kiosk check-in machine at airports; this innovation was rolled out between 2001 and 2005 and has thinned the ranks of airport ticket counter personnel, just as earlier airline web sites largely displaced travel agents and airline telephone agents; yet the rest of the employees needed to run an airline are still there, including skycaps, baggage handlers, flight attendants, pilots, air traffic controllers, and gate agents. Goods are still placed on supermarket shelves by store employees and by the drivers of delivery trucks for beer, bread, and soft drinks. Checkout lanes at retail markets are still manned by clerks rather than robots, and self-checkout lanes are few and far between. Haircuts, massages, and manicures are still exclusively the province of human workers, as are restaurants with their cooks and wait staff. Hotels still have front desk personnel, and if they offer room service, it is delivered by humans rather than robots. Far from occurring overnight, the shift to robots and job-destroying artificial intelligence is occurring at glacial speed.

Innovation alarmists write articles with titles such as "How Robots and Algorithms Are Taking Over" and predict that output will increasingly be produced by robots and computer algorithms.[66] Two visions compete in their forecasts for the next several decades: The techno-optimists predict much more rapid productivity growth as jobs are destroyed, and that the counterpart of exploding productivity growth is to be an age of persistent mass unemployment. The opposite vision extrapolates from the most recent decade and predicts "more of the same," consisting of growth rather than shrinkage of employment combined with the same historically low rate of growth of labor productivity observed during 2004–14. The symmetry of these opposing views belies the usefulness of the traditional adjectives "optimistic" and "pessimistic." The techno-optimists focus on machines replacing humans and are thus optimistic about future productivity growth while pessimistically forecasting a future of job destruction and mass unemployment. The techno-pessimist view favored here recognizes the many dimensions of advance of robots and artificial intelligence while stressing the slowness of their macroeconomic effects and the many sectors of the economy in which the interaction of workers and machines has changed slowly, if at all, in the past decade. Just as the techno-optimists are pessimistic about job growth, the techno-pessimists are optimistic that job growth will continue and that new jobs will be created as rapidly as technology destroys old jobs.

How can we choose between these sharply opposite visions? Numbers do not lie. Far from soaring toward the techno-optimists' vision of mass unemployment, the U.S. unemployment rate has declined rapidly, from 10.0 in October 2009 to 5.3 percent in June 2015, and seems likely to decline below 5.0 percent by 2016. And far from exploding as people are replaced by machines and software, labor productivity has been in the doldrums, rising only 0.5 percent per year in the five years ending in the second quarter of 2015, in contrast to the 2.3 percent per year achieved in the dot-com era of 1994–2004.[67] Now that the American economy has arrived back at a state of relatively full employment, it is hard to maintain the case that robots and artificial intelligence are creating a new class of the permanently unemployed.

The problem created by the computer age is not mass unemployment but the gradual disappearance of good, steady, middle-level jobs that have been lost not just to robots and algorithms but to globalization and outsourcing to other countries, together with the concentration of job growth in routine manual jobs that offer relatively low wages. The gradual slowing of economic growth examined in this book combines disappointing productivity growth over the past decade with a steady rise of inequality over the past three decades. In the next chapter, we turn from the technological origins of the rise and fall of productivity growth to the headwinds that have intervened to prevent most Americans from enjoying real income gains equal to the growth of economy-wide output per hour. These headwinds constitute barriers to the equal distribution of productivity gains, including the effects of rising inequality, educational stagnation, declining labor force participation, and the fiscal demands of an aging population.

Chapter 18

INEQUALITY AND THE OTHER HEADWINDS: LONG-RUN AMERICAN ECONOMIC GROWTH SLOWS TO A CRAWL

The American family is changing—and the changes guarantee that inequality will be greater in the next generation. For the first time, America's children will almost certainly not be as well educated, healthy, or wealthy as their parents.

—June Carbone and Naomi Cahn, 2014

INTRODUCTION

The impact of innovations and technological change in chapter 17 was measured by their effect on total factor productivity (TFP), which is an average for the total economy of real GDP divided by a weighted average of capital and labor inputs. There is no guarantee that every member of society will share equally in the bounty of economic progress. This chapter looks more closely at the very different outcomes that have occurred in the top of the income distribution as contrasted with the middle and bottom of the distribution. When the income gains at the top are stripped away, the growth in total income available to be divided up among the bottom 99 percent grows more slowly than income for the nation as a whole.

Just as 1970 was a watershed in chapter 17, the dividing point between rapid and slow growth in TFP, so there was a parallel and independent transition between equal growth for all before 1970 and unequal growth after 1970. By several measures, including median real wages and real taxable income in the bottom 90 percent of the income distribution, there has been no progress at all.

Other measures of income growth below the top 1 percent yield positive, rather than zero, growth—but at a rate substantially slower than averages that include the top 1 percent.

Steadily rising inequality over the past four decades is just one of the headwinds blowing at gale force to slow the growth rate of the American standard of living. The others that receive attention in this chapter are education, demographics, and government debt. Additional headwinds such as globalization, global warming, and environmental pollution are touched on more briefly. The overall conclusion of this chapter is that the combined influence of the headwinds constitutes an important additional drag on future growth going well beyond the post-1970 slowdown in the impact of innovation evident in chapter 17.

This chapter begins with a multifaceted treatment of the history of the American income distribution since the first income tax records became available 100 years ago. The rapid pace of advance in incomes at the top, particularly within the top 1 percent, can be explained by a set of factors that have boosted top incomes, including the economics of superstars, changing incentives for executive compensation, and capital gains on real estate and the stock market. Income stagnation for the bottom 90 percent of the distribution has a different set of causes, including the effect of automation in destroying middle-income jobs, an erosion of the strength of labor unions, the decline in the purchasing power of the minimum wage, the effect of imports in the shrinkage of the manufacturing sector, and the role of both high-skilled and low-skilled immigration.

The education headwind is important both by itself and as a source of growing inequality. Throughout the postwar years, starting with the GI Bill, which allowed World War II veterans to obtain a college education at the government's expense, the United States was the leader among nations in the college completion rate of its youth. But in the past two decades, the United States has stumbled, with its college completion rate now down in the league tables to tenth or below. And the American youth who enter college, regardless of whether they complete it, now face a combined burden of outstanding debt of more than $1 trillion. Educational problems are even deeper in U.S. secondary schools, which rank in the bottom half in international reading, math, and science tests administered to 15-year-olds. Most serious is the high degree of inequality in reading and vocabulary skills of the nation's children at age 5, the normal age of entrance to kindergarten; middle-class children have a spoken vocabulary as much as triple that of children brought up in poverty conditions by a single parent.

The third "demographic" headwind refers to the population viewed not as a single entity but as groups and subgroups within the total. The most important aspect of U.S. demography is the bulge in the birth rate between 1946 and 1964, the so-called "baby boom." Because the Social Security system allows retirement at three alternative ages—currently 62, 66, or 70—the effects of baby-boom retirement are spread out, beginning in 2008 and extending to 2034.[1] Other demographic issues include the shift in work patterns, as the percentage of those 55 and older who choose to remain in the work force has increased, even as labor force participation rates for all age and gender groups younger than 55 have declined. Taken together, the effect of baby-boom retirement and declining labor force participation at younger ages reduces the number of hours worked per person and implies that the standard of living defined as output per person must grow more slowly than labor productivity, which is defined as output per hour.

Government debt is the fourth headwind, because the ratio of government debt to GDP is predicted to increase steadily in the future. The growing ratio of retirees to working taxpayers will soon require remedies that change the current set of rates for Social Security taxes and/or change the calculation of benefits; the Social Security trust fund is currently projected to decline by 2034 to a level below which it cannot pay for its current schedule of obligations, whereas the Medicare trust fund will reach exhaustion level in 2030. At some point, measures must be taken to rein in persistent fiscal deficits by structural reforms that combine raising tax revenue and reducing expenditures. By definition, any increase in tax rates and/or decreases in transfer payments must reduce the growth of personal disposable income below that of pre-tax income.

The combined effects of growing inequality, a faltering education system, demographic headwinds, and the strong likelihood of a fiscal correction imply that the real median disposable income will grow much more slowly in the future than in the past. When combined with the implications of a smaller effect of innovation on productivity since 1970, there is little room for growth at all. When all the headwinds are taken into account, the future growth of real median disposable income per person will be barely positive and far below the rate enjoyed by generations of Americans dating back to the nineteenth century.

The combined effect of the four headwinds—inequality, education, demographics, and government debt—can be roughly quantified. But more difficult to assess are numerous signs of social breakdown in American society. Whether measured by the percentage of children growing up in a household headed by one parent instead of two, or by the vocabulary disadvantage of low-income preschool children, or by the percentage of both white and black young men serving time in prison, signs of social decay are everywhere in the America of the early twenty-first century. These problems are examined in this chapter, and a set of directions for policy changes is presented in the subsequent postscript.

THE FIRST HEADWIND: DIMENSIONS OF RISING INEQUALITY

Throughout this book, progress has been measured by the rate of advance of *average* real GDP per person or per hour. Such averages, or mean values, may be misleading if the pace of improvement benefits those who have high incomes more than those who have middle or low incomes. When the distribution of income, of wealth, or of any other quantity becomes skewed toward those at the top, then the median value of the series grows more slowly than the mean value. And this is just what has happened in the United States over the past four decades. In this section, we examine three separate data sources, the first based on tax records, the second on U.S. Census Bureau data, and the third on a combination of tax and census data that take into account the effect of taxes and transfers in redistributing after-tax income toward lower-income households.

Thomas Piketty and Emmanuel Saez pioneered the use of income tax data to study the evolution of top incomes compared with the incomes of those below the top. Their data for the United States go back to 1917, just a few years after the introduction of the U.S. income tax in 1914. They address the problem that the proportion of those with low and medium incomes who pay taxes varies from year to year and era to era. Their now widely accepted solution is to use standard macroeconomic data derived from the national income accounts to estimate total income and then to subtract the top incomes, based on tax records, to obtain the value of incomes below the top.[2]

Figure 18–1 summarizes the central Piketty–Saez results for most of the past century, 1917–2013. Growth rates are shown for three time intervals divided at 1948 and 1972 and for three groups, the bottom 90 percent, the top 10 percent, and the average covering all income earners. White bars display the growth rate of pre-tax income (including capital gains) for the bottom 90 percent, black bars for the top 10 percent, and gray bars for the growth in average income. Each of the three eras displays a distinctly different outcome..

During 1917–48, incomes became substantially more equal. Real incomes in the bottom 90 percent grew at 1.43 percent per year, more than double the

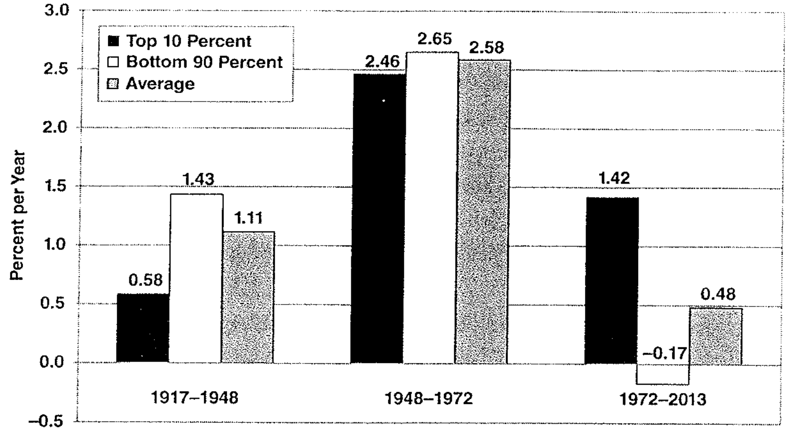

Figure 18–1. Growth Rate of Real Income, Top 10 Percent, Bottom 90 Percent, and Average, Selected Intervals, 1917–2013

Source: Calculated from Alvaredo, Facundo, Anthony B. Atkinson, Thomas Piketty and Emmanuel Saez, The World Top Incomes Database, http://topincomes.g-mond.parisschoolofeconomics.eu/, 6/25/2015. Average income for each percentile, including capital gains.

0.58 percent growth rate for the top 10 percent, with the average at 1.11 percent. This was the result of the equalizing influence of the Great Depression, World War II, and the many income-leveling programs instituted in the 1930s and 1940s, including the minimum wage, legislation encouraging the formation of labor unions, and the GI Bill, which sent millions to college and lifted them from their working class origins to middle-class status.

The remarkable fact about the middle 1948–72 period is not just that incomes grew at roughly the same rate for the bottom 90 percent, the top 10 percent, and the average, but that real incomes for each group grew so rapidly. The average growth rate of real incomes of 2.58 percent in 1948–72 was more than double the 1.11 percent growth rate of 1917–48 and more than five times the 0.48 percent growth rate of 1972–2013. The two-and-a-half decades after 1948 were a golden age for millions of high school graduates, who without a college education could work steadily at a unionized job and make an income high enough to afford a suburban house with a back yard, one or two cars, and a life style of which median-income earners in most other countries could only dream.

But all that changed after the early 1970s. A giant gap emerged between the growth rate of real income for the bottom 90 percent and the top 10 percent of the income distribution. Average real income in the bottom 90 percent was actually lower in 2013 than it was in 1972. In fact, peak real income for the bottom 90 percent of $37,053 in 2000 was barely higher than the $35,411 achieved in 1972, and by 2013, that average had declined from 2000 by 15 percent to $31,652. Meanwhile, the average real income for the top 10 percent doubled from $161,000 in 1972 to $324,000 in 2007, followed by a modest retreat to $273,000 in 2013.

A second source of data related to income inequality comes from the Census Bureau, which provides data on mean and median real household income going back to 1975. Table 18–1 compares the census growth rates for 1975–2013 and two subperiods divided at 1995, and these are compared in the same table to the Piketty–Saez data for the period since 1975. As shown in the top frame of table 18–1, mean real census income growth exceeded median growth by a substantial amount—by 0.61 percentage points during 1975–95, by 0.33 points during 1995–2012, and by 0.47 points for the two periods taken together, 1975–2012.

Growth rates of the Piketty–Saez data are reported for the post-1975 period in the bottom frame of table 18–1. The rows display respectively the growth rate of real income per taxable unit for the top 10 percent, bottom 90 percent, average of all 100 percent, and the difference between growth of the average and the bottom 90 percent. The difference is 0.70 percentage points for all three periods shown. It is interesting to compare the growth of mean census income with the growth of average Piketty–Saez income; we should expect the latter to be somewhat more rapid, for the concept includes capital gains, which

Table 18–1. Growth Rates of Real Income, Alternative Measures, 1975–2013

	1975–2013	1975–1995	1995–2013
Mean Household Income	0.77	1.15	0.35
Median Household Income	0.29	0.54	0.02
Mean minus Median	0.47	0.61	0.33
	1975–2013	**1975–1995**	**1995–2013**
Top 10 Percent	1.60	1.84	1.34
Bottom 90 Percent	−0.09	−0.01	−0.18
Average	0.60	0.68	0.52
Average minus Bottom 90	0.70	0.70	0.69

Sources: Median and mean household income from US Census Bureau, *Income and Poverty in the United States: 2013,* Table A–1. Percentile income from data underlying Figure 18–1.

are excluded in the census income data. Despite this conceptual difference, for the full 1975–2013 interval, mean census income growth of 0.77 percent per year is slightly higher than Piketty–Saez average growth of 0.60 percent.

Recently criticism of the Piketty–Saez and Census Bureau data has complained that they reflect only market income and ignore the effect of taxes and transfers.[3] Not surprisingly, an adjustment for taxes and transfers reduces the difference of income growth between the average including the top income group and the average excluding that top group. Tax rates paid by high-income individuals are substantially higher than those paid by most taxpayers, and indeed most households in the bottom half of the income distribution pay little or no federal income tax. Social Security, Medicare, and employer-paid health care premiums are transfer payments that benefit those in the middle of the income distribution, whereas food stamps, the earned-income tax credit, and Medicaid transfer payments are primarily directed to households in the bottom of the income distribution.

The most comprehensive analysis that adjusts for taxes and transfers is published regularly by the Congressional Budget Office (CBO). The concept of market pre-tax income is more comprehensive than for Piketty–Saez and the census data and rises more rapidly than the alternatives.[4] As shown in column (1) of table 18–2, CBO average pre-tax market income grows during 1979–2011

Table 18–2. Annual Growth Rate of Two Concepts of Income by Distributional Group, 1979 to 2011

Income Group	**Market Income**	**Post-Tax Post-Transfer Income**
	(1)	(2)
Top One Percent	3.82	4.05
81–99 Percentile	1.39	1.60
20–80 Percentile	0.46	1.05
1–20 Percentile	0.46	1.23
Average All Percentiles	1.16	1.48
Average 1–99 Percentile	0.87	1.28
Difference, All vs. 1–99	0.29	0.20
Difference, All vs. Median	0.70	0.43

Source: CBO, *The Distribution of Household Income and Federal Taxes, 2011* at 1.16 percent per year, substantially more quickly than the 0.70 and 0.77 percent average growth rates of Piketty–Saez and the census over a slightly longer time period. After taxes and transfers are taken into account, average income grows at 1.48 per year. As would be expected, the statement of income growth after taxes and including transfer payments has the greatest effect on the lowest income group in the 1–20 percentile, raising income growth for that group from 0.46 percent per year before taxes and transfers to 1.23 percent per year after taxes and transfers. The top 1 percent also gains from the adjustment for taxes and transfers, although not by nearly so much, and has an annual growth rate of 4.05 percent per year post-tax and transfers as compared to 3.82 percent without those adjustments.[5]

When we consider the future of American growth, we care not just about growth of average income per capita, but also about growth of income per capita for the median American household. Figure 18–2 exhibits the differences between the annual growth rate of the average and bottom 90 percent for Piketty–Saez, as well as the differences between average and median growth for the census data and for the CBO data without and with the adjustments for taxes and transfers. Because the CBO data are superior to the other data sources, and because well-being depends on income after taxes and transfers, we take the right-hand bar in figure 18–2 as most relevant.[6] It shows that the difference

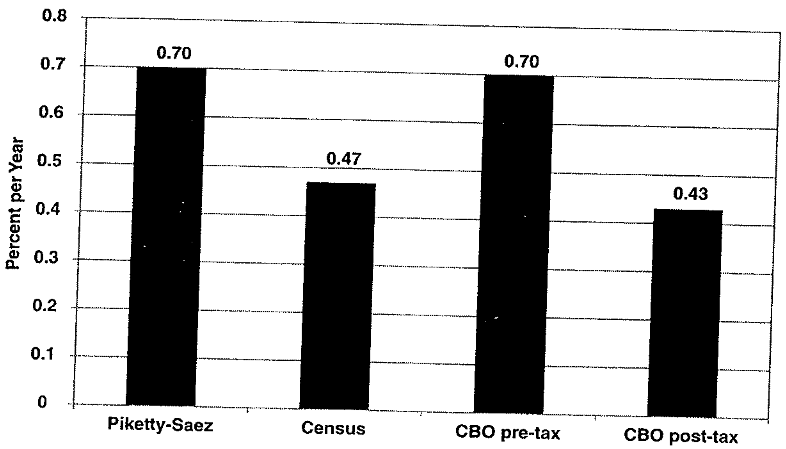

Figure 18–2. Shortfall Below Average Income Growth of Growth for the Bottom 90 percent (Piketty-Saez) and for the Median (Census and CBO)
Sources: Tables 18–1 and 18–2. CBO from 1979 to 2011, others from 1975 to 2013.

between average and median growth in the adjusted CBO data is 0.43 percent per year for 1979–2011.

If income inequality continues to grow over the next several decades as it has in the past three decades, how much slower will be the growth of median income relative to average income? The best indicator of what has happened in the past comes from the CBO data adjusted for taxes and transfers. If the future shortfall of median income growth relative to average growth were to continue at a rate of 0.4 percent, this implies that a projection of average future growth in per-person income of, say, 1.0 percent per year, would translate into a projection for median growth of 0.6 percent per year.

DOWNWARD PRESSURE ON WAGES OF THE BOTTOM 90 PERCENT

Which factors have influenced the evolution of the income distribution below the ninetieth percentile? The mid-1970s mark the turning point between an era of steadily rising wages in the middle and bottom of the income distribution to a new era during the past four decades when wages have grown little at the bottom and have increased much more rapidly at the top. The great stagnation of American wages over the last three decades has led many observers to believe that the economy is broken in a fundamental way. What caused the turnaround forty years ago?

Between 1929 and 1945 incomes at the top grew more slowly than at the middle and the bottom, creating the shift toward greater equality that Claudia Goldin and Robert Margo have called "the Great Compression." Between World War II and 1975, incomes at the top and bottom grew at roughly the same rate, and as a result, the compression lasted for about three decades. Three factors stressed by Goldin and Margo as supports for the compression were the rise of unionization and decline of both trade and immigration.[7] These three factors, which date back to the 1930s, convincingly explain the low level of inequality in the period 1945–75, and their reversal provides an important part of the explanation of increased inequality after 1975. In this section, we examine this reversal, consisting of the decline in unionization, and the rise of imports and immigration, along with two other factors generally credited as sources of increased inequality—namely, automation and the decline in the real value of the minimum wage. Subsequently, we turn to the role of education as a source of higher inequality as wage gains for college-educated workers have contrasted with wage stagnation for high school graduates and high school dropouts.

The percentage of U.S. employees in unions declined rapidly from 27 percent in 1973 to 19 percent in 1986, and then more slowly to 13 percent in 2011.[8] The falling rate of unionization has reduced wages, and particularly the median wage.[9] The decline in the rate of unionization combines market forces, particularly the shrinkage of manufacturing jobs and shift in consumer demand from goods to services, together with the aggressive anti-union stance adopted by many employers. The stagnation or outright decline in wages has been exacerbated by an increased tendency of firms, particularly in manufacturing and construction, to hire workers from temporary staffing agencies that pay relatively low wages and offer few if any fringe benefits. Firms benefit not only from lower labor costs but from increased flexibility in adjusting the supply of worker-hours to meet demand.

The share of imports in U.S. GDP increased from 5.4 percent in 1970 to 16.5 percent in 2014. Labor embodied in imports is a substitute for domestic labor. For this reason, the increase in the import share of GDP has contributed to the decline in the relative wages of unskilled and middle-skilled workers. In one particularly striking analysis, David Autor and co-authors calculated that imports from China between 1990 and 2007 accounted for about a quarter of the decline in manufacturing employment during that period and that they also lowered wages, reduced the labor force participation rate, and raised publicly financed transfer payments.[10] The inroads of imports go beyond final goods, because both firms and countries increasingly specialize in different stages of production. For instance, increases of automobile parts more than doubled between 2001 and 2014, from $63 billion to $138 billion, and caused many U.S. parts manufacturers to close their domestic factories and in some cases to "offshore" parts production to foreign countries, particularly Mexico.[11] Taken together, increased import penetration and outsourcing represent the combined effects of globalization on the levels of both employment and wages in the domestic economy. In the case of the automotive parts industry, the effects of globalization included a decline in median wages from $18.35 in 2003 to $15.83 per hour in 2013.[12]

Immigration accounted for more than half of total labor force growth in the United States over the decade between 1995 and 2005.[13] A complementary measure is that the share of foreign-born workers in the labor force steadily grew from 5.3 percent in 1970 to 14.7 percent in 2005.[14] Economic research supports the view that immigrants reduce the wages of domestic workers by a small amount and that the effect is greatest on domestic workers lacking a high school degree. Many low-skilled immigrants disproportionately take jobs and enter occupations already staffed by foreign-born workers—for example, restaurant workers and landscape services—and thus their main effect is to drive down wages of foreign-born workers, not domestic workers. The previous literature has noted the fact that among high school dropouts, wages of domestic and foreign-born workers were almost identical up to 1980, but by 2004, foreign-born workers earned 15–20 percent less.[15]

Downward pressure on wages in the bottom 90 percent would have occurred even if there had been no erosion of unionization nor a growth of imports or immigration. The steady pace of automation—the replacement of jobs by machines—would have contributed to a decline of the relative incomes of those in the bottom 90 percent. Relatively high-paying manufacturing jobs have eroded, as the share of manufacturing employment in the United States declined from 30 percent in 1953 to less than 10 percent currently. The automation effect overlaps with "skill-biased technical change" that results in the destruction of routine jobs that are close substitutes to software-driven computers, and these job losses have occurred not just in the assembly lines of manufacturing plants, but also in such routine office occupations as typist, bookkeeper, clerk, receptionist, and others. Automation did not create a permanent state of mass unemployment, as once was feared by pessimists, and the economy was able to attain an unemployment rate below 5.0 percent in the business cycle expansion that ended in 2007, and the unemployment rate in 2015 has again declined close to 5.0 percent.

Instead of massive job loss, the *composition* of jobs has changed, with more jobs created at the top and bottom of the occupational distribution and a hollowing out of the middle. This transformation has been dubbed the "polarization hypothesis" and has been extensively documented in recent years by labor economists.[16] Upper-level jobs such as those held by managers and professionals are often called "non-routine abstract" occupations. Middle-level jobs such as those held by assembly-line manufacturing workers, bookkeepers, receptionists, and clerks have been called "routine" occupations, whereas those at the bottom have been called "manual" jobs. One result of the loss of middle-skilled routine jobs is that middle-skilled workers are forced to compete for low-skilled manual jobs, thus raising the supply relative to the demand for manual workers. The result has been a decline in wages for those with relatively low skills, high school graduates and high school dropouts, as shown below in figure 18–3. The overall level of wages is reduced as the composition of employment shifts from

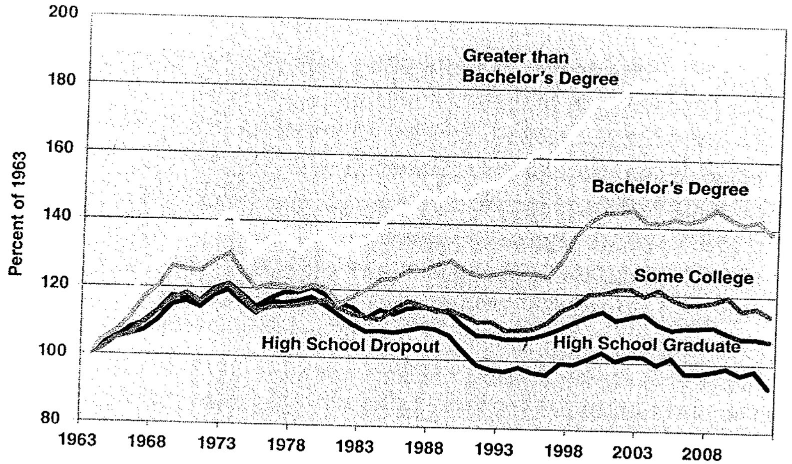

Figure 18–3. Real Weekly Earnings by Educational Attainment, 1963 = 100, 1963–2012

Source: Autor (2014b), Figure 6.

relatively well-paid manufacturing jobs to the wide range of typically low-paid jobs in retail, food services, cleaning, and groundskeeping.

Beyond the effects of deunionization, rising imports, the flow of immigrants, and automation, a fifth fact that has tended to increase inequality within the bottom 90 percent of the income distribution is the erosion of the minimum wage. Stated in constant 2011 dollars, the minimum wage decreased between 1979 and 1989 from $8.38 to $5.87. It reached a low point of $4.68 in 2006 before being raised to $7.25 in 2009. Several authors contend that the erosion of the real minimum wage accounts for much of the increase of inequality as represented by the ratio of incomes in the tenth percentile to those in the ninetieth percentile.[17]

It seems plausible that the decline of relative incomes below the ninetieth percentile since the late 1970s has been caused, at least in part, by the declining bargaining power and density of unions, by the increased importance of imports and immigration, by the inroads of automation, and by the decrease in the real minimum wage. Frank Levy and Peter Temin provide a complementary interpretation that places more emphasis on a change in political philosophy from what they call the "Detroit Consensus" of the late 1940s to the Reagan-initiated "Washington Consensus" of the early 1980s. The main point

that Levy and Temin add to our preceding summary is that highly progressive taxes, with 90 percent marginal tax rates for top-bracket earners in the 1940s and 1950s, sent a signal that high incomes were unacceptable.[18] Beginning with the Reagan tax cuts, that element of the policy support of the great compression began to erode, and CEO compensation surged ahead from twenty times average worker pay in 1973 to 257 times higher in 2013, when the average CEO pay of publicly traded companies reached $10.5 million.[19] The pay gap is even greater for retirement saving, in which it is typical for departing CEOs to receive multi-million-dollar retirement plans. A particularly blatant example was the CEO of Target, who was replaced in May 2014 after a massive credit card hacking data breach and received a retirement package of $47 million, about 1,000 times the average balance that workers at Target have saved in that company's 401(k) plan.[20]

Recently, there has been substantial publicity for the plight of fast food workers, most of whom are paid little more than the minimum wage. The bottom 20 percent of American workers classified by income earn less than $9.89 per hour, and their inflation-adjusted wage fell by 5 percent between 2006 and 2012, while average pay for the median worker fell 3.4 percent. Holding down wages is an explicit corporate strategy at many retail firms.[21] The *Wall Street Journal* writes,

> Economic changes over the past decade have led to a decline across the country in well-paying jobs, such as those in manufacturing, and an increase in jobs that pay less, such as those in hotels and food services.... Positions are increasingly being filled not with the young and inexperienced, but by older and more skilled workers who can't find other jobs.[22]

The Caterpillar Corporation has become a poster child for rising inequality. It has broken strikes in order to enforce a two-tier wage system in which new hires are paid half of existing workers, even though both groups are members of the same labor union. In contrast, there was an 80 percent increase during 2011–13 in the compensation of Caterpillar's CEO, whose quoted mantra is "we can never make enough money... we can never make enough profit."[23] Foreign companies such as Volkswagen continue to open plants in the nonunion right-to-work states. By lowering wages compared to wages in union-dominated northern states, these foreign transplant factories help keep overall U.S. manufacturing employment from declining further. But any progress in arresting the decades-long decline in manufacturing employment appears to be contingent on maintaining worker wages at about half the level that the automobile union had achieved for its workers before the bankruptcy of General Motors and Chrysler. In the 2009–2013 recovery, manufacturing regained only 600,000 of the 6 million jobs that had been lost since 2001, and most of those were contingent on hiring workers at wage rates that were substantially lower than were common in manufacturing as recently as 2001.[24]

INCREASED INEQUALITY AT THE TOP

Table 18–2 focused on the gap between the growth rate of average real income since 1975 as contrasted either with income growth at the median (i.e., fiftieth percentile) of that distribution. Much of the increase of inequality has resulted from increased skewness within the top decile. Even within the top 1 percent, income gains are much faster the higher one rises into the stratosphere of the top 0.1 percent and the top 0.01 percent. It is useful in identifying the sources of rising incomes at the top to use a three-way distinction between superstars in the sports and entertainment industries, other highly paid and highly skilled workers, and the controversial additional category of CEOs and other top corporate managers.

The economics of superstars is a concept originally invented by Sherwin Rosen, who explained the extreme skewness in occupational categories dominated by superstars as the results of particular characteristics of demand and supply.[25] On the demand side, audiences want to see the very best talent, not the second-best, so income is highly skewed because the ability of top superstars to fill large entertainment venues and to sell recordings is an order of magnitude greater than that of the second-best stars. On the supply side, the performer exerts the same effort whether ten or 10,000 witness the performance. Superstar premia reflect a particular type of skill-biased technical change. Rosen suggested that a succession of innovations going back to the phonograph boosted the size of audiences who can hear a given performance and thus increased the incomes of superstars by many multiples. The sharp rise of superstar incomes since the time of Rosen's 1981 article reflects the further development of technology, including cable TV, rentable videotapes and DVDs, Internet-based movie streaming, YouTube videos, and downloaded music.

A second group of high-income individuals also reflects the operation of the market—that is, of supply and demand. Important professions, especially top-ranked lawyers and investment bankers, earn incomes that are determined by market demand for the services provided by their firms, whether an enormous law firm such as Chicago's Sidley Austin or an investment bank such as Goldman Sachs. These market-driven professionals differ from superstars in that their product is not amplified by electronic media. They are still tied down by the need to meet in person with clients and to attend legal proceedings with adversaries in person. This second group goes beyond lawyers and investment bankers to include anyone whose individual services are in high demand, including those in publishing, design, fashion, medicine, and even in the top ranks of academics.

CEOs and other top corporate officers represent a distinct third group. An ample literature suggests that CEO pay is not set purely on the market, but rather is set by peer CEOs who sit on compensation committees. Lucian Bebchuk and Yaniv Grinstein provide a managerial power hypothesis that drives top executive pay well above the market solution.[26] The pay of the top five corporate officers in 1,500 firms increased by almost twice as much between 1993 and 2003 as their regression model could explain. These authors report the striking fact that the ratio of top-five compensation to total corporate profits for their 1,500 firms rose from 5.0 percent in 1993–95 to 12.8 percent in 2000–2002.

It is clear from the literature that the rise of executive pay is dominated by the growth in the role of stock options. Brian Hall and Jeffrey Liebman propose two alternative explanations; they juxtapose a market-driven explanation against a managerial power explanation. Their first proposed explanation is that the use of stock options has increased so dramatically because corporate boards want to tighten the relationship between pay and performance. Their second proposed explanation, complementary to their first, is that boards want to increase CEO pay and choose option grants as a "less visible" method that is less likely to incite stockholder anger.[27]

There are doubtless overlaps and interactions among the superstar, top talent, and CEO explanations of rising inequality. After becoming rich for whatever reason, those at the pinnacle of the income distribution multiply their earnings by investing in the stock market and more esoteric investments such as private equity and hedge funds. Wealth gains were particularly extreme between 1983, when the S&P 500 stock market average was at 120, and 2000, when the S&P 500 average for the year reached 1477. This represents a real rate of return including dividends of 14.3 percent per year.[28] Not only do households below the ninetieth percentile of the income distribution own few stocks (except indirectly through retirement plans), but they are also prone to perverse market timing. A Federal Reserve study showed that more than 5 million households sold out of the stock market when it was low in 2009–10 and that only those in the top 10 percent of the income distribution have increased their holdings of stock since then.[29] Some of this tendency of lower-income households to "bail out" of the market when it is low may come from a necessity to liquidate assets in the face of unemployment caused by a business cycle slump.

A recent study by the Pew Research Center quantified the trajectory of real wealth increases by dividing American households into an upper group comprising 21 percent of households, a middle group comprising 46 percent, and a lower group accounting for the remaining 33 percent.[30] For the large middle group, the real inflation-adjusted value of wealth stagnated over three decades, growing only from $94,300 in 1983 to $96,500 in 2013. Over that thirty-year period, real wealth in the bottom group actually fell, from $11,400 to $9,300. In contrast, the top group enjoyed an exact doubling of real wealth, from $318,100 in 1983 to $639,400 in 2013. Though the emphasis of this book on the standard of living primarily refers to real income per person, the evolution of real wealth cannot be ignored, for the "safety net" aspect of wealth accumulation has a profound effect on welfare by providing self-insurance against the loss of a job or an accident or illness that reduces the ability to earn income. Real wealth stagnation for the bottom 80 percent of the U.S. income distribution is a powerful indicator supporting the view that the growth in well-being has slowed in the past three decades.

EDUCATION AS A SOURCE OF GROWING INEQUALITY

The preceding two sections examined sources of downward pressure on wages and incomes in the bottom 90 percent and the sources of rising relative incomes in the top 1 percent of the income distribution. In addition, a bifurcation has occurred within the bottom 90 percent, with wage stagnation and decline in the bottom percentiles combined with faster income growth in the eightieth and ninetieth percentiles, although not nearly so rapid as in the top 1 percent. Education is the chief source of this spreading out of the income distribution, for growth in the compensation of those who complete a four-year college degree has far outpaced those who drop out of high school. Earnings outcomes of those who have two-year college degrees, who have achieved partial completion of

four-year college degrees, and those who have high school diplomas have experienced intermediate outcomes between the extremes represented by four-year college completion at the top and high school dropouts at the bottom.

The analysis of the rewards earned by workers who have different amounts of educational attainment starts with the basic proposition that the earnings of workers is determined by their productivity—that is, how much they produce from an hour of work. The value of that hour depends on demand and supply—that is, the value to the employer of what an employee can produce and the number of workers who are capable of completing the required tasks. As the percentage of Americans who complete college has increased, the supply of college graduates has risen relative to those with less educational attainment. That increase in relative supply was particularly rapid between 1964 and 1982 and was sufficiently fast relative to the increase in the relative demand for college graduates to cause the college wage premium to shrink slightly in the 1970s. After 1982, the growth in the relative supply slowed and that in relative demand increased, so the college wage premium increased between 1982 and 2000. This rise in the college wage premium has been sufficient to explain essentially all of the rise in earnings of those at the ninetieth percentile relative to those at the tenth percentile between 1984 and 2004.

Figure 18–3 shows the evolution of the real wage of full-time male workers in five education groups expressed as a ratio to the real wage of that group in 1963.[31] The lines are arrayed from top to bottom by the amount of education, with the top line plotting the real wage of those with education beyond the four-year bachelor's degree and the bottom line depicting wage changes of high school dropouts. Each point plotted represents the wage relative to 1963, so the final point of 97 percent plotted for 2012 for high school dropouts represents a 3 percent wage decline from 1963 to 2012, whereas the final point of 188 percent for those having earned beyond a bachelor's degree indicates a 88 percent increase in the real wage since 1963. The spreading apart of the five lines, showing greater wage gains with a higher educational attainment, indicates that the relative demand for highly educated graduates grew more quickly than their relative supply. It is important to note that the increasing earnings of those who have a college degree or greater increased relative to wages of high school graduates and dropouts not just because the college graduates were doing so well, but also because the groups at the bottom were doing so poorly.

The growth of earnings in the five groups did not proceed at a uniform pace. The upsurge in college graduate real wages occurred in two relatively short periods, first between 1964 and 1972 and then between 1996 and 2000. Between 1972 and 1996, and then again after 2000, the real wage of college graduates stagnated. For high school graduates, there were several phases in the evolution of the real wage: an increase during 1964–72, then a long slow decline from 1972 to 1990, stagnation to 1996, a partial recovery during 1996–2000, and then stagnation again between 2000 and 2012. The outcomes for those who have some college lie in between those for college graduates and high school graduates but are closer to the latter, whereas high school dropouts had a real wage trajectory that fell gradually, between 1974 and 2000, to about 10 percent below that for high school graduates. The erosion in wages for high school graduates and dropouts is a result of all the factors already cited—the decline in unionization and the minimum wage combined with the increase in imports and immigration, together with the ongoing role of automation.[32]

We can divide the real wage for bachelor's degree recipients by that for high school graduates to plot the evolution of the college wage premium relative to its 1963 value, as in figure 18–4. The college wage premium increased over the past half-century, but not at a uniform pace. After an initial upsurge between 1964 and 1967, the premium stagnated until 1973, when by 1982 it declined back to the 1963 level. It then increased steadily from 100 percent

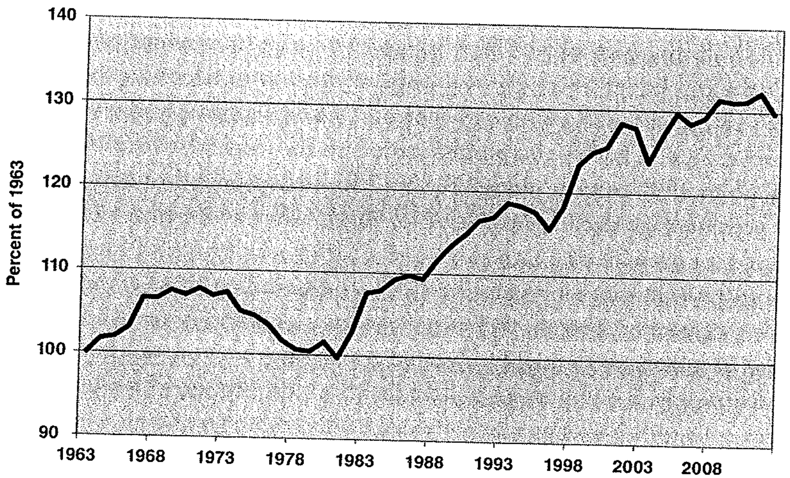

Figure 18–4. Real Weekly Earnings, Percent Ratio of College Graduates to High School Graduates, 1963=100, 1963–2012

Source: Calculated from data underlying Autor (2014b), Figure 6.

to 128 percent of the 1963 level between 1982 and 2001, followed by little further growth. The decline in the premium in the 1970s can be attributed to the rise in the relative supply of college graduates that took place in the 1960s and 1970s. The increase in the premium from 1982 to 2001 coincides with a period of relatively slow growth in the relative supply of college graduates, and the sharp increase between 1996 and 2001 may also reflect the rapid increase in the demand for skills during the dot-com boom of the late 1990s. The flattening of the premium after 2005 appears to be the result of a renewed increase in the relative supply of college graduates, but it also reflects the decline in the demand for non-routine abstract jobs that set in after 2000.[33]

As the supply of college-educated workers has increased, a growing fraction of college graduates have been forced to accept jobs that do not require a college education. As shown by Paul Beaudry and co-authors, after 2000, there was a decline in the share of college graduates working in non-routine abstract occupations and an increase in those working in manual jobs.[34] This represents a sharp turnaround from the 1990s and placed further downward pressure on the wages paid for routine manual work. Beaudry explains the decline in the demand for non-routine abstract workers as the complement of the post-2000 decline of investment in high-tech information and communication technology equipment in the investment bust that followed the late 1990s dot-com boom.

So far we have expressed real wages and the college wage premium relative to their values in 1963. What is the dollar equivalent of these values? The monetary value of the college wage premium is substantial. The 2012 annual full-time earnings gap between college graduates and high school graduates was $35,000 for men and $23,000 for women. A two-earner household with both husband and wife having college degrees would have an annual earning $58,000 higher than a two-earner household consisting of two high school graduates. The present discounted value of obtaining a college degree relative to a high school degree by 2008 had reached $590,000 for men and $370,000 for women.[35] These substantial rewards to college graduation include the additional income earned by those who gain postgraduate professional degrees, for which college graduation is a necessary prerequisite.

The effect of education on inequality extends beyond the direct effect of schooling on earnings in the current generation, because well-educated parents tend to bestow numerous advantages on the next generation. Typically, college-educated men and women marry each other, earn two incomes enhanced by the college degree, and have their children after marriage rather than out of wedlock. They nurture their children and read to them, enhancing their vocabulary advantage over children from less educated parents. Highly educated parents also have the money to enrich their children's lives through exposure to museums, sports, music lessons, and a variety of books. They tend to live in suburbs where local schools provide a richer diet of educational choices, including more counseling to pass Advanced Placement tests and to gain admission to top-ranked universities, where the admissions process tends to discriminate in favor of alumni. Scores on the SAT college admission tests tend to be highly correlated with parental income. All these advantages reduce social mobility and establish a self-perpetuating educational elite, for almost all high income families send their children to four-year college, whereas virtually none of the poorest Americans do so. College completion for households in the top quarter of the income distribution rose between 1970 and 2013 from 40 percent to 77 percent, whereas for those in the bottom quarter, it increased only from 6 percent to 9 percent.[36]

EDUCATION AS THE SECOND HEADWIND

The higher earnings of those with a college and postgraduate degrees reflects their higher productivity on the job. For the economy as a whole, this implies that aggregate productivity growth depends positively on the growth of educational attainment. Every high school dropout becomes a worker who is unlikely ever to earn much more than the minimum wage for the rest of his or her life.

The surge in high school graduation rates was a central driver of twentieth-century economic growth. But gains in overall educational attainment have become slower since 1980, implying that education has become a headwind in the sense that its smaller contribution to economic growth has reduced the growth rate of productivity and per-person income. This section examines the slowdown in the advance of educational attainment, the evidence that the U.S. education system is turning out students who have poor achievement levels compared to their international peers, and the role of tuition inflation and college student debt as an impediment to college completion, particularly for those from low- and middle-income family backgrounds.

Since Edward Denison's first 1962 attempt at measurement, growth accounting has recognized the role of increasing educational attainment as a source of economic growth.[37] Claudia Goldin and Lawrence Katz estimate that educational attainment increased by 0.8 years per decade over the eight decades

between 1890 and 1970. Over this period, they also estimate that the improvement in educational attainment contributed 0.35 percentage points per year to the growth of productivity and output per person.[38] In separate research, I have adjusted Denison's estimates for 1913–79 to current BLS methodology and find an average contribution of education of 0.38 percent per year, almost identical to that of Goldin and Katz.

The increase of educational attainment has two parts, that referring to secondary education and the other relevant for higher education. High school graduation rates increased from less than 10 percent of youth in 1900 to 80 percent by 1970, and the percentage of 18-year-olds receiving bona fide high school diplomas has since fallen, to 74 percent in 2000, according to James Heckman. He found that the economic outcomes of those who earned not a high school diploma but rather a General Education Development (GED) certificate performed no better economically than high school dropouts and that the drop in graduation rates could be explained, in part, by the rising share of youth who are in prison rather than in school.[39] The United States currently ranks eleventh among the developed nations in high school graduation rates and is the only country in which the graduation rates of those aged 25–34 is no higher than those aged 55–64.[40]

The role of education in holding back future economic growth is evident in the poor quality of educational outcomes at the secondary level. A UNICEF report lists the United States eighteenth of twenty-four countries in the percentage of secondary students that rank below a fixed international standard in reading and math. The international PISA tests in 2013, again referring to secondary education, rated the United States seventeenth in reading, twentieth in science, and twenty-seventh in math.[41] A recent evaluation by the ACT college entrance test organization showed that only 25 percent of high school students were prepared to attend college as evidenced by adequate scores on reading, math, and science.

At the college level, the problems combine an interaction between a decline in the international league tables of college graduation rates with the issues of affordability and student debt. During most of the postwar period, a low-cost college education was within reach of a larger fraction of the population than in any other nation, thanks both to free college education made possible by the GI Bill and to minimal tuition for in-state students at state public universities and junior colleges. The United States led the world during most of the last century in the percentage of youth completing college. The percentage of the 25–34 age group who have earned a BA degree from a four-year college has inched up in the past fifteen years from 25 percent to 32 percent, but the United States is now ranked twelfth among developed nations, after having been ranked second as recently as 2000.[42]

And the future does not look promising. The cost of a university education has risen since 1972 at more than triple the overall rate of inflation.[43] Between 2001 and 2012, funding by states and localities for higher education declined by fully a third when adjusted for inflation. In 1985, the state of Colorado provided 37 percent of the budget of the University of Colorado, but in 2013, it provided only 9 percent. Even when account is taken of the discounts from full tuition made possible by scholarships and fellowships, the current level of American college completion has been made possible only by a dramatic rise in student borrowing. Americans now owe $1.2 trillion in college debt. Though a four-year college degree still pays off in a much higher income and lower risk of unemployment than for high school graduates, still more than half of recent college graduates were unable to find a job requiring a college education. This "underemployment rate" was 56 percent for 22-year-olds, declining to about 40 percent for 27-year-olds, and the inability of so many college graduates to find appropriate jobs is consistent with the evidence, already cited, from Beaudry, Green, and Sand, arguing that there has been a reversal in the demand for non-routine abstract cognitive skills since 2000.[44]

Students taking on large amounts of student debt face two kinds of risks. One is that they fall short of the average income achieved by the typical college graduate through some combination of unemployment after college and an inability to find a job in their chosen field of study. Research has shown that on average, a college student taking on $100,000 in student debt will still come out ahead by age 34, with the higher income made possible by college completion high enough to offset the debt repayment. But that break-even age becomes older if future income falls short of the average graduate. There is also completion risk. A student who drops out after two years never breaks even, because wages of college dropouts are little better than those of high school graduates. These risks are particularly relevant for high-achieving students from low-income families—Caroline Hoxby has shown that they seldom apply to elite colleges, which are prepared to fund them completely without debt, so they wind up at subpar colleges, loaded with debt.[45]

The poor achievement of American high school graduates spills over to their performance in college education. Many of the less capable enter

two-year community colleges, which currently enroll 39 percent of American undergraduates, whereas the remaining 61 percent enroll in four-year colleges. The Center on International Education Benchmarking reports that only 13 percent of students in two-year colleges graduate in two years, although the percentage rises to 28 percent after four years. The low graduation rates reflect the need for most students to work part-time or full-time in addition to their college classes, as well as the poor preparation of the secondary graduates who enter community colleges. Most community college students take one or more remedial courses.[46]

Just as the defects of American secondary education make successful college careers less likely, so does the great inequality of financing of American elementary education feed through to poor high school performance and an excessively large rate of high school dropouts. The American elementary school system is financed by property tax revenue that allows wealthy suburbs to provide lavish facilities to their students who already have a head start thanks to their parents' income and home tutoring, whereas the students from poverty families often face acute budget cutbacks and school closings as a result of shrinking inner city enrollments and inadequate local property tax revenue. The United States is also failing to follow the lead of other nations in providing free preschool education. Across the rich nations, an average of 70 percent of 3-year-olds are enrolled in some kind of education program, whereas in the United States, that percentage is 38 percent.[47]

THE THIRD HEADWIND: DEMOGRAPHY

The demographic headwind refers to a set of forces that have changed hours per person (H/N), thus driving a wedge between the growth of productivity and the growth of output per person. The organizing principle to understand its significance is a definitional identity that relates total output (Real Gross Domestic Product or Y) to aggregate hours of work in the total economy (H) and the total population (N):

$$\frac{Y}{N} \equiv \frac{Y}{H} \cdot \frac{H}{N}. \tag{1}$$

Equation (1) states the truism that the standard of living measured by output per person (Y/N) by definition equals labor productivity or output per hour (Y/H) times hours per person (H/N). By decomposing output per person into productivity and hours per person, equation (1) helps clarify the relationship between chapters 17 and 18 of this book. In chapter 17, the past, present, and future of productivity (Y/H) growth was related to innovation, the fundamental driver of higher output per worker-hour. Chapter 18 identifies economic headwinds that change productivity, those that change hours per person, and those that influence neither aggregate variable but rather, in the case of inequality, reduce median real income growth relative to the economy-wide average.

The crucial H/N term can be further decomposed into hours per employee (H/E), the employment rate as a percentage of the labor force (E/L), and the labor force participation rate (L/N):

$$(2) \qquad \frac{H}{N} \equiv \frac{H}{E} \cdot \frac{E}{L} \cdot \frac{L}{N}$$

The most important demographic events in the postwar United States were the baby boom of 1946 to 1964, the influx of women into the labor force between 1965 and 1995, and the retirement of the baby boom generation starting around 2008. The entry of the baby boom generation into the work force in the 1970s boosted hours per person, while the influx of women permanently raised the *level* of hours per person and raised its *growth rate* during the transition period, roughly 1965–95. Positive growth in hours per person allowed output per person to grow faster than labor productivity, as in equation (1).

The retirement of the baby boomers will reduce hours per person independently of any other cause over a long transition period extending from 2008 to 2034. There is more to the demographic headwind, however, than the retirement of the baby boomers. The labor force participation rate (L/N) fell from 66.0 percent in 2007 to 62.9 percent for the full year 2014 and further to 62.6 percent in June 2015. Because the working-age population is 250 million, the decline in L/N by 3.4 percentage points (66.0 minus 62.6) implies a loss of 8.5 million jobs, most of them permanently.

Economic research has concluded that about half the decline in the participation rate was caused by the retirement of the baby boomers and the rest by a decline in the participation of those younger than 55. Those who have stopped looking for jobs and have thus dropped out of the labor force consist of workers who have lost their jobs in an economic setting in which they do not expect to be employed again, and a sizeable fraction of them have been able to obtain Social Security disability benefits.[48] To call attention to the plight of these victims of deindustrialization, in late July 2013, President Obama toured several Rust Belt cities that have lost most of their manufacturing jobs base. Cities such as Galesburg, Illinois; Scranton, Pennsylvania; and Syracuse, New York now mainly rely on government, health care, and retail jobs. In Scranton, 41.3 percent of those older than 18 have withdrawn from the workforce, and in Syracuse, that percentage is an even higher 42.4 percent.[49] The devastating effect of manufacturing plant closures throughout the Midwest is captured by remarks of the newly appointed British consul-general in Chicago, who toured the Midwest during the autumn of 2013, in the first three months of his four-year term. Asked for impressions of his travels, he said, "What surprised me most was the deterioration and decay of the former one-factory small and middle-sized manufacturing towns."[50]

What does the 2007–14 experience imply for the future? We will optimistically assume that the dropping out of those younger than 55 has run its course, and that the only source of the further decline in the participation rate will be baby boomer retirement. Several scholars have estimated that the retirement of the baby-boom generation will cause hours per person (H/N) to decline by –0.4 percent per year, and this implies that future growth in average output per person (Y/N) will be 0.4 points slower than that of labor productivity (Y/H). At the end of this chapter, the effects of declining labor force participation will be combined with those of the other headwinds to provide a projection for future growth in median real disposable income per person.[51]

THE FOURTH HEADWIND: REPAYING DEBT

The future reckoning for government finance will arrive over the next several decades. The official projections of the Congressional Budget Office (CBO) currently estimate that the federal ratio of debt to GDP will stabilize between 2014 and 2020 and then rise steadily to 100 percent by 2038. But the CBO estimates paint too rosy a scenario, because its forecast of future growth in output, and hence in federal tax revenue, is too optimistic. The CBO, as a result, has understated the future rise in the debt: GDP ratio. For 2024, the official CBO forecast is a ratio of 78 percent; mine is 87 percent. For 2038, the CBO is at 100 percent; my forecast is roughly 125 percent.[52]

But even the CBO projects that trouble lies ahead beyond 2020. The Medicare trust fund is predicted to reach a zero balance in 2030, and the zero-balance date for Social Security is projected to occur in 2034. By definition, any stabilization of the federal debt-GDP ratio, compared to its likely steady increase with current policies, will require more rapid growth in future taxes and/or slower growth in future transfer payments. This is the fourth headwind, the near inevitability that over the next several decades, disposable income will decline relative to real income before taxes and transfers, reversing the trends of the past quarter-century. This is the inevitable consequence of an aging population and slowing population growth.

A sole focus on the federal debt ignores the unfunded pension liabilities of many of America's states and localities. The bankruptcy of Detroit has led municipal bond experts to ask whether Illinois and Chicago could be far behind, not to mention other large states that have massive unfunded pension liabilities. A reasonable, albeit arbitrary, forecast is that the future growth in tax rates and/or slower growth of government transfers will reduce the growth rate of disposable income in the future by 0.1 percent per year relative to income before taxes and transfers.

SOCIAL CHANGE AT THE BOTTOM OF THE INCOME DISTRIBUTION

The first part of this chapter addressed the issue of steadily rising inequality in the United States by presenting a set of alternative measures of mean vs. median income. However, the status of those at the middle and bottom of the income distribution goes beyond a lack of growth in money income. Social conditions are decaying, and clearly there is a chicken and egg two-way causality between stagnant incomes and social dysfunction. A lack of job opportunities may be responsible for declining marriage rates and for the sharp increase in the percentage of children living with only one parent. But also social problems may disqualify some for employment, especially if a prison term is involved.

The decline of marriage as an institution among Americans who lack a college education is relevant to the future rate of productivity growth, because children—particularly boys—who grow up in households lacking a father are more likely to drop out of high school and become engaged in criminal activity. An important source of this sociological change is the evaporation of steady, high-paying blue-collar jobs. Partly because men without a college education have lacked the incomes and steady employment to be attractive marriage partners, and partly because women have become more independent as opportunities in the labor market have opened up for them, fewer couples are getting married. Much of this reflects the importance that females place on having an employed spouse, as well as that there are only sixty-five employed men for every

100 women of a given age. Among young African Americans, there are only fifty-one employed men for every 100 women, reflecting in large part the high incarceration rates of young black males. Many young people view financial stability as a prerequisite for marriage, so the reluctance to marry interacts with the wage stagnation of the past three decades.[53]

For white high school graduates, the percentage of children born out of wedlock increased from 4 percent in 1982 to 34 percent in 2008 and from 21 percent to 42 percent for white high school dropouts. For blacks, the equivalent percentages are a rise from 48 percent to 74 percent for high school graduates and from 76 percent to 96 percent for high school dropouts.[54] Not only is the rate of marriage declining, but almost half of all marriages fail. The number of children born outside of marriage is drawing equal with the number of children born within marriage. June Carbone and Naomi Cahn summarize the implications for the future:

> The American family is changing—and the changes guarantee that inequality will be greater in the next generation. For the first time, America's children will almost certainly not be as well educated, healthy, or wealthy as their parents, and the result stems from the growing disconnect between the resources available to adults and those invested in children.[55]

Charles Murray has documented the decline of every relevant social indicator for the bottom third of the white population, which he calls "Fishtown" after a poor area of Philadelphia. He admirably presents his data in a series of charts that uniformly extend from 1960 to 2010. For the white population of Fishtown, the percentage of married couples in which at least one spouse worked forty or more hours in the previous week declined from 84 percent in 1960 to 58 percent in 2010. The breakup of the family is documented by three complementary indicators all referring to the 30–49 age group: percent married down from 85 percent to 48 percent, percent never married up from 8 percent to 25 percent, and percent divorced up from 5 percent to 33 percent.[56]

Murray's most devastating statistic of all is that for mothers aged 40, the percentage of children living with both biological parents declined from 95 percent in 1960 to 34 percent in 2010. The educational and inequality headwinds interact, leading to the prediction of a continuing slippage of the United States in the international league tables of high school and college completion rates.

Separately, the growth of college student debt leads to a prediction of delays in marriage and child birth and a decline in the rate of population growth, which aggravates the other sources of the future growth slowdown, particularly the fiscal headwind.

Other sources support Murray's emphasis on social decline in the bottom third of the white population. A recent study showed that between 1979 and 2009, the cumulative percentage of white male high school dropouts who had been in prison rose from 3.8 percent to 28.0 percent. For blacks over the same time interval, the percentage who had been in prison rose from 14.7 percent to 68.0 percent. That is, fully two-thirds of black male high school dropouts experience at least one spell in prison by the time they reach 40 years old. For black graduates from high school (including those with GED certificates), the percentage in prison rose from 11.0 percent to 21.4 percent.[57]

Any kind of criminal record, and especially time in prison, severely limits the employment opportunities available to those whose prison sentences are ending. According to the FBI, no less than a third of all adult Americans have a criminal record of some sort, including arrests that did not lead to convictions; this stands as a major barrier to employment.[58] The increased sophistication of electronic records make it easier for prospective employers to learn about stains in the past of a prospective job applicant. The diminished probability of employment in turn feeds back to the likelihood of marriage, for women are not attracted to men who have no capability of earning an income from legal activity.

> State laws prohibit the employment of convicted felons in occupations ranging from child- and dependent-care providers to barbers and hairdressers. Some states also cut off their access to public employment, which has been an important source of work for inner-city minorities.... Many employers are wary of employing convicted felons because of mounting case law delineating their liability risks for "negligent hiring."[59]

OTHER HEADWINDS

Discussions of headwinds often turn to two additional barriers to growth that are difficult to quantify, "globalization" and "energy/environment." This section places these additional headwinds in perspective without attempting to quantify their importance.

Globalization is difficult to disentangle from other sources of rising inequality. Plant closings caused by offshoring are responsible for part of the demographic headwind by causing prime-age workers to leave the labor force when their one-factory town experiences a plant closure. There has been a major loss of high-paying manufacturing jobs that long antedates the 2008 financial crisis and 2007–9 recession. Roughly half of the 7 million person loss of manufacturing jobs between 2000 and 2011 occurred before 2008.[60] The period 2000–2007 witnessed the maximum impact of the increase in Chinese manufacturing capacity that flooded the United States with imports, boosted the trade deficit, and caused plant closings and ended the chance of millions of workers to enjoy middle-income wages with no better than a high school diploma. The main reason why the economy experienced an economic expansion rather than contraction in the years leading up to 2007 was the housing bubble, which allowed many of the displaced manufacturing workers to obtain temporary jobs in the construction industry.

Globalization is also responsible for rising inequality through another channel. The United States has benefited from foreign investment, particularly in the automotive industry, but this has been directed almost exclusively at the right-to-work states, largely in the south, where foreign firms are free to pay workers whatever they want. Wages of $15 to $20 per hour, compared to the old standard of $30 to $40 per hour achieved before 2007 in union states such as Michigan and Ohio, are welcomed by residents of the southern states as manna from heaven, and new plant openings are greeted by long lines of hopeful workers at the hiring gates. Globalization is working as in the classic economic theory of factor price equalization, raising wages in developing countries and slowing their growth in the advanced nations.

Another potential headwind concerns the possible effects of global warming and other environmental issues, and a possible tailwind has emerged in the form of greatly increased U.S. domestic oil and natural gas production as a result of horizontal fracking. Though the extent and likely effects of global warming are subject to debate, there is little doubt that they are occurring and will create weather events—whether coastal flooding or more frequent and violent tornadoes—that will reduce future economic growth and raise insurance premia. Future carbon taxes and direct regulatory interventions such as the CAFÉ fuel economy standards will divert investment into research whose sole purpose is improving energy efficiency and fuel economy. Regulations that require the replacement of machinery or consumer appliances with new versions that are more energy-efficient but operationally equivalent impose a capital cost burden. Such investments do not contribute to economic growth in the same sense as such early twentieth-century innovations as the replacement of the icebox by the electric refrigerator or the replacement of the horse by the automobile.

One of the world's experts on global warming, William Nordhaus, has quantified its effects on economic growth. A surprising aspect of his research is that the impact of a 3 °C warming in the global temperature in the next seventy years would reduce global real GDP per person by only around 2.5 percent.[61] That translates as an annual subtraction of growth of –2.5/70, or 0.036 of a percentage point per year, trivial compared to the estimates in this paper of a negative effect of –0.4 percent for demography as a result of baby-boom retirement. Nordhaus's estimates are based on a hypothetical failure of worldwide policy to take explicit new measures to fight global warming.

Vast new fields of gas and oil made possible by fracking have created a cheap source of energy. In assessing the importance of fracking, a distinction must be made between oil and gas fracking. The price of oil is set in world markets, so additional oil discoveries may ultimately make the United States oil-independent but will not make oil prices lower in the United States than in the rest of the world. Because natural gas cannot be easily transported between continents, the gas fracking revolution in the United States is more of a boon. The cheaper price of gas that is unique to the North American continent will lead to a welcome substitution of gas for oil and coal, helping to reduce the growth of carbon emissions as well as reducing costs in energy-intensive industries.

CONCLUSION: FORECASTING FUTURE GROWTH IN THE STANDARD OF LIVING

This chapter on the headwinds and the preceding chapter 17 on the slowing pace of innovation have identified a set of forces that will retard future U.S. economic growth compared to the past. In this concluding section, we consider the implications for the future growth of labor productivity (output per hour) and the standard of living (output per person) over the next two to three decades, roughly the period 2015–40. It is not enough to project future growth in average output per person if inequality continues to increase, because rising inequality implies that median growth in output per person will be less than average growth. Similarly, in the event that future taxes are raised and/or transfer payments are cut to limit the rise in the ratio of public debt to GDP, then

real median disposable income will grow more slowly than real median income before taxes and transfers are taken into account.

By definition, our forecast of growth in output per person must equal the forecast growth in output per hour plus projected growth in hours per person. Thus our forecasting task begins by translating the analysis from chapter 17 on the past behavior of output per hour—that is, labor productivity—into a projection of future productivity growth. As shown in the first four lines of table 18–3, the record of actual productivity growth since 1948 can be divided into four distinctly different eras. Rapid growth of 2.71 percent per year prior to 1970 contrasts with relatively slow growth of 1.54 percent per year between 1970 and 1994. Then came the dot-com–related revival to a rate of 2.26 percent between 1994 and 2004, followed by the end of the revival with growth in 2004–15 of 1.00 percent, even slower than during 1970–94.

A substantial portion of chapter 17 was devoted to the contrast between the 1994–2004 productivity revival decade and the 2004–14 slowdown decade. Our conclusion was that the revival was a one-time event that is unlikely to be repeated. Most of the benefits of the conversion of business methods and practices from the age of paper and filing cabinets to the new age of web-connected computers, digital storage, and digital search, came together in the upsurge of productivity growth during 1994–2004. The transition to slower growth after 2004 was pervasive and included a decline in business dynamism in the form of the reduced

Table 18–3. Actual and Forecast Growth Rate of Output per Hour, 1948–2040

	Actual Growth	Education Adjustment	Growth Net of Education Adjustment
1. 1948–1970	2.71		
2. 1970–1994	1.54		
3. 1994–2004	2.26		
4. 2004–2015	1.00		
5. Weighted Average of 1970–94 and 2004–15	1.38	–0.30	1.08
6. Forecast Growth 2015–40			1.20

Source: Output is GDP from NIPA Table 1.1.6. Hours are an unpublished series for total-economy hours obtained from the BLS.
Note: Growth rates in lines 1–4 refer to the second quarter of each year shown.

entry of new firms, the decline to near zero in the growth of manufacturing capacity after a temporary upsurge in the late 1990s, a decline in net investment to far below the postwar average, a greatly reduced rate of decline in the ratio of computer prices to performance, and the apparent demise of Moore's Law governing the rate of improvement in the density of transistors on computer chips.

The implication of these dimensions of temporary upsurge followed by slowdown is that the productivity revival decade of 1994–2004 is not relevant to our task of forecasting future productivity growth. Instead, we treat that decade as the climactic bringing together of the fruits of digital invention that could only happen once, that was not repeated in the 2004–14 decade, and that is unlikely to be repeated in our twenty-five-year forecast interval. Leaving this decade aside, we instead consider the implications of the other years of the post-1970 era—namely, 1970–94 and 2004–15—which exhibit 1.54 and 1.00 percent per year productivity growth, respectively. As a precedent for future growth, these two intervals (weighted by the number of years in each interval) average out at 1.38 percent per year, as shown in line 5 of table 18–3.

However, to base our forecast for the future on this 1.38 percent average rate would ignore the implications for productivity of the slowdown in the growth of educational attainment emphasized by Goldin and Katz and others, as well as recent evidence, already reviewed, of an upward shift in the percentage of college degree holders who upon graduation are unable to obtain a job requiring a college degree. Dale Jorgenson and associates have estimated that future productivity growth will be reduced by 0.3 percent per year by the diminished contribution of education, and in table 18–3, we apply their −0.3 percent adjustment factor in line 4 to mark down the 1.38 actual growth rate to a 1.08 percent adjusted rate that is relevant in its implications for future productivity growth.[62] Rounding up slightly to veer in the direction of optimism, the forecast growth rate of productivity for 2015–40 is taken to be 1.20 percent per year. Though this rate may appear to be pessimistic compared to the short-lived revival years of 1994–2004, it represents a goal that seems ambitious from the perspective of mid-2015. In quarterly data, the annual growth rate of productivity in the five years ending in the second quarter of 2015 was only 0.50 percent.

We now turn in table 18–4 to the implications of a 1.20 percent future growth rate of productivity to the likely growth in output per person, which depends on the behavior of total hours per person. To arrive at a forecast of the future rate of decline of hours per person, we choose not to speculate on any further decline in the participation rate of the sub-55 age group and rather to

Table 18–4. Actual and Forecast Annual Growth Rates of Productivity and the Standard of Living

	Actual 1920–1970	Actual 1970–2014	Forecast 2015–2040
1. Labor Productivity *(Y/H)*	2.82	1.62	1.20
2. Hours per Person *(H/N)*	−0.41	0.15	−0.40
3. Real GDP per Person *(Y/N)*	2.41	1.77	0.80
4. Median vs. Average	0.20	−0.43	−0.40
5. Median Real GDP per Person	2.61	1.34	0.40
6. Real Disposable Income vs. GDP	−0.36	0.12	−0.10
7. Real Median Disposable Income per Person	2.25	1.46	0.30

Notes for actual 1920–2014 values. Forecasts for 2015–2040 are discussed in the text.
Lines 1–3. From data underlying Figure 16–1 and 16–2. See Data Appendix.
Line 4. 1920–1970 from data underlying Figure 18–1. 1970–2013 from Table 18–2, bottom row, column 2.
Line 5. Sum of Line 3 and Line 4.
Line 6. 1920–2014 from NIPA Table 2.1, deflated by the GDP deflator. 1920–70 refers to 1929–70.
Line 7. Sum of Line 5 and Line 6.

extrapolate hours per person based only on the fact that the baby-boom generation will retire on a roughly predicable schedule during 2015–34. This will cause hours per person to decline at a rate of −0.4 percent per year, as shown in table 18–4, line 2. The implication, as shown on line 3, is that real GDP per person will grow at 0.8 percent per year during 2015–40, much slower than the growth rates of 2.41 percent achieved during 1920–70 and of 1.77 percent per year since 1970.

Income became more equal during 1920–70, as shown in table 18–4, line 4, when the "great compression" boosted median income growth per person at a rate almost 0.2 percent faster than average income growth per person. Then, during 1970–2014, income became less equal. When adjusted for taxes and transfers, median income growth per person proceeded at a rate 0.43 percent per annum slower than average growth. To project future growth in median real income per person, we need to conjecture whether income inequality will continue to widen or whether the trend toward more unequal incomes slows down or stops entirely. The factors that have driven rising inequality are powerful and look likely to continue. Globalization will continue to cause imports and off-shoring to erode the base of middle-income jobs, as will the gradual but steady advance of robots, big data, and artificial intelligence, as discussed in chapter 17.

Beyond a continuation of past trends, the outlook for inequality confronts the elements of social change discussed in this chapter. Just as we have taken the past performance of actual productivity growth to provide our guidepost to the future, we do so for inequality and assume that median real income per person will grow at 0.4 percent per year slower than average real income per person, roughly the same rate as calculated from recent research for the growth of median versus average income during 1979–2011. The result of this 0.4 point subtraction is median growth of 0.4 percent per year compared to 0.8 percent for average growth, as shown on line 5 of table 18–4. The final adjustment is to recognize the inexorable rise in the federal government debt to GDP ratio. There is no way of knowing now how these fiscal problems will be resolved, let alone when or how quickly. In line 6 of table 18–4, we assume that a future fiscal adjustment by raising taxes and lowering transfer payments will result in disposable income that grows 0.1 percent slower than pre-tax income, roughly reversing the 1970–2014 period when disposable income grew at 0.12 percent faster than pre-tax income.

The bottom line of table 18–4 represents the combined effect of the projections made for future growth in productivity, hours per person, inequality, and fiscal policy over the next twenty-five years. Our choices in the right column of table 18–4 represent an attempt to weigh the precedents set by past actual performance together with likely future trends such as baby-boom retirement, low social mobility, the implications of single-parent households for the future achievement levels of the next generation of adults, and the fiscal adjustments made necessary by an aging population.

Figure 18–5 summarizes the differences between the actual outcome, now displayed for the near-century between 1920 and 2014, and the projected values. The left two bars are for the past and the future and refer to the annual growth rate of output per hour. The next two bars show the past and future for output per person, and so on for growth in median real income per person and real disposable income per person. The shortfall of projected future growth as compared to actual past growth reflects the decline in the impact of innovation on productivity as examined in chapter 17 and the headwinds discussed in this chapter. In short, the innovation slowdown and four headwinds—inequality, education, demography, and debt—convert the historical record that achieved 2.1 percent growth of income per person for nearly a century to a bleak future in which median real disposable income will barely grow at all.

As with any forecast, the projected growth of labor productivity and the subtractions for the effects of the headwinds could be too high or too low. The

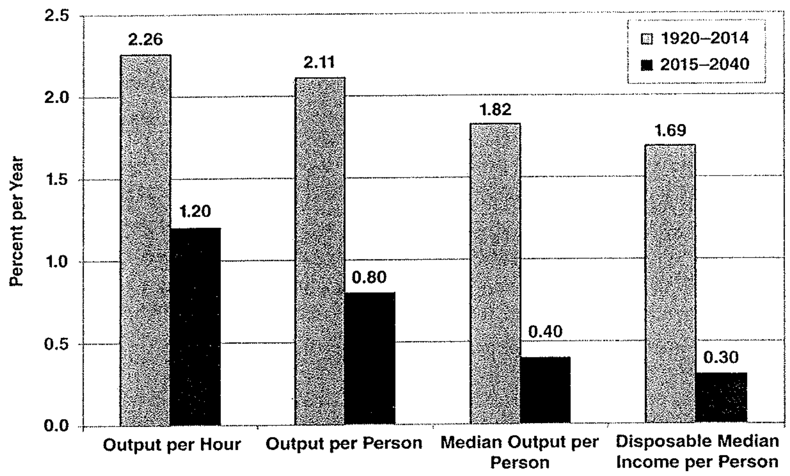

Figure 18–5. Annual Growth Rate of Alternative Real Income Concepts, Actual Outcomes 1920–2014 and Projected Values 2015–2040
Source: Data underlying Table 18–4.

choice for future productivity growth of 1.20 percent per year, though slow by the standards of 1920–70 or 1994–2004, exceeds the actual 1.00 percent growth rate registered over the past eleven years and far exceeds the 0.50 percent per year growth rate achieved over the past five years. The subtraction for declining hours per person reflects only baby-boom retirement and optimistically assumes that the fifteen-year decline in the labor force participation rate of those younger than 55 has come to an end. The subtraction for inequality assumes that the forces driving the divergence in top incomes from median incomes will continue and will not be exacerbated by the increasing share of children growing up in single-parent households. The final subtraction for future fiscal retrenchment is modest and does not fully reflect the feedback from slowing real GDP growth in restricting the future growth in federal tax revenues, nor the need for fiscal retrenchment at the state and local government level. Overall, though the bottom-line forecast of a mere 0.3 percent growth rate in real disposable median income may seem startling, each step in this "exercise in subtraction" is well supported by our analysis of chapters 17 and 18 and is also consistent with the history of American economic growth over the past decade.[63] Are there policies that could mitigate the sources of slowing growth? We turn to a set of feasible policy options in the postscript.

Postscript

AMERICA'S GROWTH ACHIEVEMENT AND THE PATH AHEAD

DECLINING GROWTH: INNOVATION AND THE HEADWINDS

This book's title, *The Rise and Fall of American Growth,* might seem to imply a sense of success followed by failure, but that is not the message to be conveyed. What is remarkable about the American experience is not that growth is slowing down but that it was so rapid for so long, and that the United States has maintained its productivity leadership over the leading nations of western Europe since the late 19th century. Instead, the rise and fall of growth are inevitable when we recognize that progress occurs more rapidly in some time intervals than in others. There was virtually no economic growth for millennia—until 1770—slow growth in the transition century before 1870, and for the United States, remarkably rapid growth in the revolutionary century ending in 1970, followed by slower growth since then. American growth slowed down after 1970 not because inventors had lost their spark or were devoid of new ideas, but because the basic elements of a modern standard of living had by then already been achieved along so many dimensions, including food, clothing, housing, transportation, entertainment, communication, health, and working conditions.

The 1870–1970 century was unique: Many of these inventions could only happen once, and others reached natural limits. The transition from carrying water in and out to piped running water and waste removal could only happen once, as could the transition for women from the scrub board and clothes line to the automatic washing machine and dryer. After 1970, innovation excelled in the categories of entertainment, information and communication technology: Television made its multiple transitions to color, cable, high-definition, flat screens, and streaming, and the mainframe computer was joined by the personal computer, the Internet and the World Wide Web, search engines, e-commerce, and smartphones and tablets.

The timing of the stream of innovations before and after 1970 is the fundamental cause of the rise and fall of American growth. In recent years, further downward pressure on the growth rate has emerged from the four headwinds that are slowly strangling the American growth engine. Rising inequality has diverted a substantial share of income growth to the top 1 percent, leaving a smaller share for the bottom 99 percent. Educational attainment is no longer increasing as rapidly as it did during most of the 20th century, which reduces productivity growth. Hours worked per person are decreasing with the retirement of the baby-boom generation. A rising share of the population in retirement, a shrinking share of working age, and longer life expectancy are coming together to place the federal debt/GDP ratio after the year 2020 on an unsustainable upward trajectory. These four headwinds are sufficiently strong to leave virtually no room for growth over the next 25 years in median disposable real income per person.

PERSPECTIVES ON AMERICAN ECONOMIC PERFORMANCE

The United States emerged from World War II with an unprecedented economic and political dominance. From 1948 to 1973, the Great Compression in the income distribution brought rapid increases in real wages from the top to the bottom, and the world's first mass consumer society was created: Ordinary citizens could finally afford the cars, televisions, appliances, and suburban houses that industry stood ready to produce. Enlightened government made a free college education and low-cost mortgages available for returning veterans and in a whirlwind of legislation passed the Civil Rights Act of 1964 and the Voting Rights Act of 1965 and, also in 1965, introduced Medicare for senior citizens and Medicaid for those in poverty. Women moved into the labor market and into higher education and the professions with such success that by 2010, 58 percent of those receiving bachelor's degrees were female.

The industrial leadership of the United States during the 1870–1970 century has given way to a mixture of advance and decline. Though manufacturing employment has declined steadily as a share of the economy, American inventions have established a new phase of dominance. Though few computers and smart devices are being manufactured in the United States, almost all the software and organizational creativity of the modern digital age has originated within U.S. borders. Of the ten most valuable companies in the world, eight are located in the United States. The continuing stream of innovations spawned by America's inventors is fueled by funding from America's sophisticated and aggressive venture capital industry, and due credit should be given to government-funded science and to the role of the U.S. Department of Defense in the early development of the Internet.

Contemporary America exhibits many other signs of health besides frenetically active markets for inventors and entrepreneurs. Research and development is at an all-time high as a percent of GDP, and the development of new drugs by the pharmaceutical industry is also dominated by American firms. Innovations in the exploration and production of shale oil and gas have reduced America's import dependence faster than was predicted only a few years ago. America's top private and public research universities have a near monopoly in the league table of the world's top thirty institutions of higher education. Finally, America's population is not aging as rapidly as are populations in western Europe or Japan, both because of a higher fertility rate and thanks to continued immigration from around the world.

All these advantages are sources of solid strength for the U.S. economic system that are likely to persist over our forecast horizon of the next quarter-century. In the shorter run, the U.S. unemployment rate has declined from 10 percent in late 2009 to almost 5 percent—compared to more than 11 percent in the Eurozone. Jobs are being created at the rate of 2.5 million per year. Assuming the continuation of slow inflation, there is still room for unemployment to decline further and for employment to grow before running into the constraints set by slowing population growth and declining hours of work per person.

THE POTENTIAL FOR POLICY CHANGES TO BOOST PRODUCTIVITY AND COMBAT THE HEADWINDS

The potential effects of pro-growth policies are inherently limited by the nature of the underlying problems. The fostering of innovation is not a promising avenue for government policy intervention, as the American innovation machine operates healthily on its own. There is little room for policy to boost investment, since years of easy monetary policy and high profits have provided more investment funds than firms have chosen to use. Instead, educational issues represent the most fruitful direction for policies to enhance productivity growth. Moreover, overcoming aspects of the education headwind matters not only for productivity growth. A better educational system, particularly for children at the youngest ages, can counter increasing inequality and alleviate the handicaps faced by children growing up in poverty.

The inexorable rise of inequality can be countered at the top by higher taxes on the highest earners who have captured so much more of the income pie than was true forty years ago. At the bottom, an increase in the minimum wage and an expansion of the earned-income tax credit can divert more of the economic pie to those in the bottom half. The decline in marriage, which stems in part from the absence of men, many of whom languish in prison, can be countered to some extent by a reform of incarceration policy and a further movement toward drug legalization. Creative policies to reform education are available from preschool to middle school to higher education. Inequality can be alleviated and productivity growth promoted by combating overly zealous and regressive regulations. The demographic headwind that is shifting the share of the population from working to retirement status can be offset by new immigration policies that substantially raise legal limits while emphasizing the education and work experience of would-be immigrants. The post-2020 fiscal reckoning does not require higher payroll taxes or lower retirement benefits, as new sources of fiscal revenue are available from drug legalization, increased tax progressivity, tax reform that eliminates most tax deductions, and a carbon tax that provides incentives to reduce emissions.

TOWARD GREATER EQUALITY OF OUTCOMES

Increasing inequality combines rapidly rising incomes at the top with stagnant incomes at the middle and bottom. Policies to influence inequality face a fundamental asymmetry, because we want to make those in the bottom 99 percent more productive and find ways for them to earn higher incomes, but we have no parallel desire to make those in the top 1 percent less productive, nor to find ways for them to contribute less to the economy and to society. Policies to increase the equality of outcomes narrow the disparity between top and bottom by reducing disposable income at the top and raising it at the bottom.

Progressivity of the Tax System

The share of income earned by the top 1 percent almost tripled, from 8 percent in 1974 to 22 percent in 2014, and the share of the top 0.01 percent quintupled

over the same period, from 1 percent to 5 percent.[1] Many high-income earners, particularly sports and entertainment stars, earn pure rents (the excess of their pay over the next best job they could obtain). CEO pay as a ratio to average worker pay increased from 22 times in 1973 to 352 times in 2007, and further evidence of rent is seen in that the ratio increased by a factor of 16 when CEOs were performing the same functions as before.[2] One policy solution is to tax these rents by introducing "super-bracket" tax rates applicable to those making more than, say, $1 million and another higher rate for those making more than $10 million. Another pro-equality policy change would be to make tax rates on dividends and capital gains equal to those on regular income, as was in effect between 1993 and 1997, thus ending the current anomaly whereby Warren Buffett pays a lower tax rate than his secretary. Still another step toward equity would be to eliminate the provision in tax law that exempts from taxation the increase in the value of financial assets passed on through inheritance.[3]

The Minimum Wage

The most frequently proposed policy measure to boost the growth rate of real wages at the bottom is to increase the federal minimum wage, which is currently set at $7.25. This is 12 percent less than the average value of the minimum wage in the 1960s, expressed in 2014 prices.[4] Over the same 50 years, real compensation per hour rose by 115 percent, an indicator of how inadequate was the legislated real value of the minimum wage in keeping up with overall compensation.[5] Standard economic theory implies that an increase in the minimum wage would raise the unemployment rate of the low-wage workers. However, a substantial body of economic research indicates little or no employment effect. The current economic situation of 2015–16 is a particularly appropriate time to raise the minimum wage, as the U.S. labor market currently has a record number of job openings and is creating low-skill jobs at a relatively rapid rate.

Earned Income Tax Credit

The EITC rewards low-income parents for working and has had a large positive effect on net income for its beneficiaries. It has also achieved dramatic improvements in the well-being of children in those families, including a reduction in the incidence of low birth weight, an increase in math and reading scores, and a boost in college enrollment rates for the children who benefited. Making the EITC more comprehensive and generous is widely supported, and recent research indicates that expanding the EITC is a complement to raising the minimum wage, not a substitute for it.[6]

Incarceration

The imprisonment rate, expressed as a share of the population, in the United States is eight to ten times higher than in the largest European countries. Incarceration is an issue that relates to inequality, for those sent to prison are primarily ill-educated and poor. Their imprisonment prevents them from completing their education and deprives them of contact with their children, and when they are released, their criminal record becomes a major handicap to finding employment. Even what jobs are available are usually of the most menial type, for years of incarceration cause job skills to erode. A research study found that 60 percent of those released from prison were unemployed one year after release.[7] Individual lives are ruined by sentences that are too long and by parole and probation policies that are too inflexible. Cash bail policies condemn many poor people accused of crimes to spend time in prison while awaiting sentencing. Several million children grow up while a parent is in prison, hampering their childhood development.

The U.S. prison system is estimated to cost taxpayers $74 billion per year, using up government revenue that could otherwise be used to address a host of measures directed at inequality.[8] The policy solutions to this aspect of inequality are unique in that they would reduce government spending rather than require new expenditures. Some of the saving could be devoted to programs to deal with drug addiction and mental health issues experienced by those released from prison. It is not enough for the needed reforms to impose shorter sentences, for decades of imposing long sentences have left many older men in prison who are now of little threat to society. Only a widespread movement toward pardoning can make an appreciable dent in the prison population.

Drug Legalization

The case for drug legalization rests on the high costs and limited effectiveness of drug prohibition. Jeffrey Miron and Katherine Waldock have tallied up the costs of drug prohibition as of 2010 at $88 billion per year.[9] Legalization would allow half of this to be avoided through saving in police enforcement, court costs, and the capital and personnel costs of the portion of the prison system required to house drug offenders. The other half of the potential savings

represents currently foregone tax revenue, assuming that legal drugs would be taxed at rates comparable to tobacco. These cost estimates do not count the less tangible effects of incarceration for drug offenses, such as the loss of civil liberties and the negative consequences of a criminal record for future income and employment.

TOWARD GREATER EQUALITY OF OPPORTUNITY

Preschool Education

Though preschool is universal for 4-year-olds in countries such as Britain and Japan, in the United States, only 69 percent of that age group is enrolled in preschool programs, ranking U.S. participation as number 26 among OECD countries, with the poorest children least likely to be enrolled. The United States is ranked 24th for the fraction of 3-year-olds participating in preschool programs, with a 50 percent enrollment percentage as compared to at least 90 percent in such countries as France and Italy. The United States ranks poorly not just in the age at which children enter preschool, but also in class sizes and per-pupil expenditures.[10]

The benefits of preschool education apply to all students, but particularly to those growing up in low-income families. Children of poor parents, who themselves have a limited educational attainment, enter kindergarten at age 5 suffering from a large vocabulary gap that limits their performance in elementary and secondary education and that leads to high dropout rates—and often to criminal activity. Age 5 is too late for the educational system to intervene in the learning process, for by then, the brain has already developed rapidly to build the cognitive and character skills that are critical for future success. Poor children lack the in-home reading, daily conversation, and frequent question/answer sessions so common in middle-class families, particularly those in which both parents have completed college.

James Heckman and others have studied follow-up data on outcomes of children who have completed experimental preschool programs.[11] They estimate that one program yielded a per-year return of 7 percent to 10 percent, consisting of increased school and career achievement together with reduced costs of remedial education as well as lower health and criminal justice system expenditures. They argue that preschool education for at-risk children from poor families pays for itself in the long run, and that each dollar yields a higher return than if that dollar were added to spending on elementary and secondary education. Effective preschool education is devoted not only to vocabulary and other learning skills, but also to "character skills such as attentiveness, impulse control, persistence and teamwork." [12]

Secondary and Higher Education

Preschool comes first, because each level of disappointing performance in the American educational system, from poor outcomes on international PISA tests administered to 15-year-olds to remedial classes in community colleges, reflects the cascade of underachievement that children carry with them from one grade to the next. No panacea has emerged in the form of school choice and charter schools, although there has been much experimentation—with some notable successes in which children from low-income backgrounds have earned high school diplomas and gone on to college.[13] An important component of the inequality and education headwinds is the U.S. system of financing elementary and secondary education by local property taxes, leading to the contrast between lavish facilities in rich suburbs which coexist with run-down, often outmoded schools in the poor areas of central cities. A shift of school finance from local to statewide revenue sources would reduce inequality and improve educational outcomes. Ideally, schools serving poor children should have the resources to spend more than those serving well-off children, rather than less as at present.

High costs and rapidly escalating student debt have emerged as the leading problems in American higher education. Despite substantial scholarship aid, particularly at wealthy private universities, by 2015 student debt had reached $1.2 trillion, and young people faced with hundreds of dollars per month in student loan repayments are delaying household formation, marriage, childbirth, and home ownership. The most promising policy initiative would be to shift student loans to a system of income-contingent repayment administered through the income tax system. Though federal student loans have recently introduced income-contingent repayment options, those originating in the private sector offer no such options, and so far relatively few students have chosen the income-contingent option. Australia serves as a model: College education is free for students while in college, after which a fraction of the cost is repaid through the income tax system, based on a percentage of taxable income. During a spell of unemployment or if income is below a particular threshold, no payment is due until an adequate job is found. The system is subsidized in that 20 percent of the outstanding debt is never repaid.[14]

Regressive Regulation

Throughout American economic life, regulatory barriers to entry and competition limit innovation by providing excessive monopoly privileges through copyright and patent laws, restrict occupational choice by protecting incumbent service providers through occupational licensing restrictions, and create artificial scarcity through land-use regulation. They contribute to increased inequality while reducing productivity growth. There is broad agreement among policy experts that copyright laws are overreaching by criminalizing copyright infringement and prohibiting noncommercial copying—an anomaly in the Internet Age. Patent laws have expanded too far by protecting software and business methods.[15]

Morris Kleiner has calculated that the percentage of jobs subject to occupational licensing has expanded from 10 percent in 1970 to 30 percent in 2008.[16] Licensing reduces opportunities for employment, limits the ability of new entrants to create small businesses, and restricts upward mobility for lower-income individuals. By contributing to a reduction in the rate of entry of new firms, licensing is one of the sources of the decline in "business dynamism" noted in the literature cited in chapter 17. Edward Glaeser has called restrictive zoning and land use regulations a "regulatory tax" that transfers wealth from the less affluent to more affluent and promotes housing segregation by keeping poor people away from rich people and that, by inflating housing prices, encourages potential residents to move away from the most productive metropolitan areas to less productive areas, where housing is cheaper.[17] All these instances of excessive regulation are relevant to inequality, for they redistribute income and wealth to those who are protected by their copyrights, patents, licenses, and land-use restrictions. Rolling back these and other excessive regulations is one available policy lever to alleviate inequality and boost productivity growth, with the qualification that many of the regulations are imposed at the state and local level and are outside the direct reach of federal government policy.

THE DEMOGRAPHIC AND FISCAL HEADWINDS

The demographic headwind reduces hours per person with the retirement of the baby-boom generation and, over the past decade, a decline in the labor force participation of those younger than 55. The fiscal headwind is caused by an increase in the ratio of people in retirement who do not earn incomes or do not pay income taxes to working people who do earn incomes and do pay taxes. Policy solutions include immigration, to raise the number of tax-paying workers, together with tax reforms that would raise revenue and improve tax equity. A carbon tax, desirable on environmental grounds to reduce carbon emissions, has the side benefit of generating substantial revenue to help alleviate the fiscal headwind.

Immigration

Reform of immigration can be accomplished in a way that raises the average skill level of the working-age population and that thus contributes to the growth of labor productivity. One avenue for reform would be to end the practice of denying residency to foreign-born graduates of U.S. universities, a "self-imposed brain drain." A promising tool to promote high-skilled immigration and raise the average quality of the U.S. labor force would be one such as the Canadian point-based immigration system, in which a point calculator is used to rate each immigrant applicant based on his or her level of education, language skills, and previous employment experience, among other criteria.[18] The definition of skills could be broad and could include blue-collar skills, many of which are currently in short supply in the U.S. The potential to increase the number of immigrants is revealed by the contrast between Canada's annual immigration quota, equal to 0.8 percent of its population, and the U.S. annual legal limit, equal to 0.3 percent of its population.

Tax Reform

A substantial gain in equity and in tax revenue could be achieved by adopting Martin Feldstein's longstanding recommendation to limit "tax expenditures"—his term for the many deductions built into the income tax system. All deductions, in contrast to tax credits, make tax savings rise with income, so eliminating the deductions will improve the equity of the tax system. Feldstein provides details of one plan that would raise federal tax revenues by $144 billion annually without ending charitable deductions.[19]

A carbon tax, widely supported as the most direct method of controlling carbon emissions, can address the fiscal headwind. Revenue from a carbon tax can be used to avoid raising payroll taxes or to avoid reducing retirement benefits. The CBO has estimated that a tax of $20 per ton of carbon dioxide emissions would raise $115 billion per year.[20]

The Fiscal Reckoning

The fiscal headwind originates in increased life expectancy and in the rising ratio of retired people to working people. A fiscal fix can come from three sources of extra tax revenue—the specified increases proposed above in taxes on income at the top, tax reform that eliminates or sharply limits tax deductions, and a carbon tax. Revenue from all three sources is available to stabilize the federal debt-GDP ratio and to fund the most important policy reform—the provision of universal preschool with special tutoring and enrichment programs for very young children in the poverty population. To the extent that new tax revenues are obtained by raising taxes on top incomes and by tax reforms that mainly affect the top half of the income distribution, they provide revenue to stop the growth of the debt-GDP ratio without reducing the disposable income of the median income earner.

Final Thoughts

Table P–1 summarizes 10 categories of proposed policy intervention, linking each to the related headwinds. In addition, for 7 out of 10 of the policy categories, the words "productivity growth" appear in the table, indicating that the policy category has the potential to boost the growth rate of labor productivity by increasing labor skills and human capital. These categories include a more generous EITC that improves the learning environment of poor children, policies to keep people out of prison and shorten their sentences, reforms at all levels of education, combating regressive regulations, and a shift in immigration

Table P–1. Policy Directions to Address the Headwinds and Slow Productivity Growth

Tax System Progressivity	Inequality and Fiscal
Minimum Wage	Inequality
Earned-Income Tax Credit	Inequality and Productivity
Incarceration and Drug Legalization	Inequality, Demographic, Fiscal, and Productivity
Pre-School Education	Inequality, Education, and Productivity
Public School Financing	Inequality, Education, and Productivity
Income-Contingent College Loans	Inequality, Education, and Productivity
Regressive Regulations	Inequality and Productivity
Immigration	Demographic, Fiscal, and Productivity
Tax Reform	Inequality and Fiscal

policy toward nearly automatic admission of those who have high levels of education and skills.

The sources of slow productivity growth, rising inequality, and declining hours of work per person rest on fundamental causes that will be difficult to offset. There is no claim here that even were all proposed policy initiatives implemented, median disposable real income per person would be boosted by more than a few tenths of a percent above the rate that would occur without these policy changes. Yet, whatever their effect on economic growth, these measures, taken together, would create a more equal, better-educated society, together with new sources of tax revenue to resolve the fiscal headwind and pay for new high-priority government programs—particularly preschool education.

ACKNOWLEDGMENTS

My lifelong interest in the measurement and sources of economic growth can be traced back to my graduate school job at MIT in the summer of 1965, and my first note of gratitude is to Frank Fisher and Edwin Kuh for hiring me as an assistant on their growth project. These acknowledgments are written almost exactly fifty years ago to the month after I first noticed the doubling of the U.S. output-capital ratio between the 1920s and the 1950s and the accompanying sharp discontinuous jump in total factor productivity, puzzles that pose the questions addressed in this book and in particular in Chapter 16 on the "Great Leap Forward." My intellectual debts begin with John Kendrick for his epochal 1961 book that compiled the core data on U.S. output and inputs back to 1869 upon which we still rely today for the years prior to the late 1920s. Edward Denison inspired my interest in the sources of growth, and the controversial issues that Denison debated in 1967 with Zvi Griliches and Dale Jorgenson formed the basis for a line of research that has continued throughout my career. From his role in hiring me for my first academic job to his untimely death in 1999, Griliches was my intellectual mentor and inspiration.

The book's central theme that the great inventions of the late nineteenth century lifted everyday life out of tedium and drudgery has an unusual origin. Sometime in the 1980s my wife and I stayed at a bed and breakfast in southwest Michigan, where there was a rotating bookshelf of books for guests to leave and pick up. It was there that I discovered Otto Bettmann's little known but classic book *The Bad Old Days: They Were Really Terrible,* full of illustrations of the perils of nineteenth century life, from locomotive boilers blowing up to milk being diluted with water and chalk. Bettmann's book more than any other source was the inspiration for my 2000 article, "Does the New Economy Measure Up to the Great Inventions of the Past?"

In turn, the idea of extending the theme of the great inventions into a book-length project was first suggested to me by David Warsh, a distinguished journalist who specializes in keeping track of the economics profession and its evolving ideas, and by Seth Ditchk, economics editor of the Princeton University Press (hereafter PUP). Within a week of my conversations with them at the AEA meetings in Chicago in early 2007, I described the book as a "figment" in an e-mail on January 10, 2007, to my colleague Joel Mokyr, who is the editor of the PUP series on economic history, and he immediately invited me to do the book for his series. It took forever for me to come up with a formal prospectus and chapter outline, and this was circulated for comment early in 2009, followed by the PUP contract in October, 2009.

Meanwhile Joachim Voth suggested that we jointly organize a conference in May 2010 at his home university in Barcelona around the theme of how to quantify the value of new inventions, and he cleverly titled the conference "Cornucopia Quantified." A session at the conference was devoted to two trial chapters of my book, written from a very different outline than has emerged in the present volume. I am grateful for all the ideas that I picked up at the conference, especially the comments at the session on my book chapters by David Edgerton, Mokyr, and Voth.

While the process of writing the chapters that appear here did not begin until the summer of 2011, as long ago as 2008 I began hiring one or more research assistants each year to find, compile, and highlight the book and article sources. My deep gratitude extends to all of those who worked as RAs on the book, including Ryan Ayres, Andrea Dobkin, Burke Evans, Tyler Felous, Robert Krenn, Marius Malkevicius, William Russell, Andrew Sabene, Neil Sarkar, Spencer Schmider, Conner Steines, John Wang, Scott Williams, Edwin Wu, and Lucas Zalduendo.

The book might never have been completed but for the released time and RA financial support provided by the Kauffman Foundation. I am grateful to Robert Litan, who encouraged me to apply for an initial grant and to Dane Stangler for supplemental support of the last stages of writing and editing the manuscript.

As chapters emerged numerous distinguished economists agreed to read them, and I have worked hard to incorporate the suggestions of all those who read chapters, including David Autor, Steven Davis, Ian Dew-Becker, David Dranove, Benjamin Friedman, Robert Gallamore, Joshua Hausman, Richard Hornbeck, Megan McCarville, Valerie Ramey, Hugh Rockoff, Ian Savage, Joseph Swanson, Burt Weisbrod, and Mark Witte.

Singled out for special thanks is Robert M. Solow, who supervised my MIT PhD thesis that was devoted to the puzzle of the 1920–50 doubling of the output-capital ratio, the same "great leap forward" phenomenon studied in this book's Chapter 16. During the summer of 2014 Solow not only read five chapters of the book manuscript but also celebrated his 90th birthday.

When I sent him the first draft of Chapter 16, it struck me that in a way I was submitting a much improved version of my PhD thesis forty-seven years late!

My colleague and PUP series editor Joel Mokyr was consistent in his encouragement and provided many constructive comments. The two referees for the PUP, Alex Field and Lou Cain, made many contributions to the final manuscript. I am especially grateful to Field not just for his trenchant comments but for his own discoveries of the rich trove of inventions and other dimensions of progress that occurred during the 1930s. Cain's suggestions were uniformly helpful, and he deserves credit for the final chapter organization of the book.

Seth Ditchik as Princeton University Press editor provided not just the inevitable nagging as chapters were slow to appear during 2011–13, but he maintained a healthy skepticism at my initial attempts to find an appropriate title for the book. The final title is his idea, and he deserves full credit for it and for many other aspects of the book, large and small, too many to recount. Thanks also go to Madeleine Adams, the developmental editor; Karen Fortgang, production editor; Samantha Nader, editorial assistant; and to Pete Feely and his staff who facilitated the conversion of the book manuscript into print.

My ultimate thanks go to my wife of 52 years, Julie, who did much more than tolerate the piles of books that littered my home office for four years. She has been a sounding board for many of the ideas in the book and a sharp and constructive critic right up to the last stages. The dedication to her at the beginning of the book, with its reference to a Gershwin song, is a symbol of our mutual fondness for the Great American Songbook, yet another achievement of America's great leap forward from the 1920s to the 1950s.

Robert J. Gordon
Evanston, Illinois
August 2015

DATA APPENDIX

ABBREVIATIONS IN SOURCE NOTES TO FIGURES AND TABLES

In the source notes to the figures and tables throughout the book, HSUS refers to the *Historical Statistics of the United States, Millennial Edition*, Cambridge University Press, accessed online through the Northwestern University Library. SAUS refers to the Statistical Abstract of the United States, Government Printing Office, of the designated year. NIPA refers to the National Income and Product Accounts, accessible at bea.gov.

SOURCES FOR SPECIFIED FIGURES

This data appendix provides sources for the data series involving the combination of several different data sources into new time series and index numbers. Sources for figures and tables that display data sources copied from primary sources are listed underneath each figure and table.

FIGURE 1–1

Growth rates over the listed intervals of time are taken from the data developed for figure 16–1 as described hereafter.

FIGURE 1–2

Growth rates over the listed intervals of time are taken from the data developed for figure 16–5 as described hereafter.

FIGURE FOR ENTR'ACTE BETWEEN PARTS I AND II

Output refers to real GDP, population refers to the working-age population (ages 16+) from the monthly BLS Current Population Survey, and hours of work refer to total economy hours, a quarterly unpublished series obtained each quarter from the BLS. Shown are Kalman trends for these series, developed by extracting from each series its correlation over time with the gap between that actual and natural rates of unemployment. Development of the series for the natural rate of unemployment is described in Gordon (2013).

FIGURE 16–1

Real GDP 1889–1929, Kendrick, Table A-XXII. 1929–2014, NIPA Table 1.1.6. Trend 1870–1928 calculated by linking to Berry (1988) for 1870–1889.

Population 1870–1998 HSUS series Aa7, linked to U.S. Census Bureau for 1998–2014.

Hours of work 1889–1948, Kendrick, Table A-XXII. 1948–2014 unpublished BLS series for total economy hours. Trend 1870–1928 calculated by assuming that hours per member of the population were unchanged 1870–1889.

FIGURE 16–2

All series are ratios of actual values to 1870–1928 trends, using the same data as figure 16–1.

FIGURE 16–3

Actual output per hour and its trend are taken from figure 16–1.

The real wage for 1891–1929 is from measuringworth.com and refers to the average nominal wage of production workers in manufacturing divided by the Consumer Price Index.

The nominal wage per hour for 1929–2014 is obtained by taking total employee compensation from NIPA Table 1.10, line 2, and dividing it by the index of hours as described above in the sources for figure 16–1. This is converted into a real wage series by use of the Personal Consumption Deflator from NIPA Table 1.1.4.

FIGURE 16–4

Actual GDP is taken from the sources of figure 16–1. "Original Capital" is the same as the "Official Capital" line as plotted in figure A–1. Sources are described in the next section of this Data Appendix. "Revised Capital" in figure 16–4 corresponds to the line in figure A–1 labelled "Add Government Capital," with methods described in the remainder of this Data Appendix.

FIGURE 16–5

Total factor productivity is the geometrically weighted average of the ratio of real GDP to labor input and the ratio of real GDP to capital input, with respective weights of 0.7 and 0.3.

Labor input consists of hours from the sources of Figure 16–1 multiplied by an index of labor quality, taken from the "educational productivity index" of Goldin-Katz (2008, Table 1.3, column 2, p. 39). The Goldin-Katz index is available for 1915–2005. Our educational index is extrapolated backward from 1915 to 1890 using the Goldin-Katz 1915–1940 growth rate, and it is extrapolated forward from 2005 to 2014 using the Goldin-Katz 1980–2005 growth rate.

Capital input consists of the new capital series described in the rest of this Data Appendix, shown for 1920–1970 in figure A–1 by the line labelled "Add Government Capital."

ADJUSTMENTS TO CAPITAL INPUT

The official data on the U.S. capital stock are provided by the Bureau of Economic Analysis Fixed Asset accounts (BEAFAA) back to 1925 and show that the quantity of capital input in the private economy actually *declined* between 1929 and 1945. These data greatly underestimate the increase in capital input between 1929 and 1945, and hence they overestimate the jump between the 1920s and 1950s in the average productivity of capital and of total factor productivity (hereafter TFP). In this section, we develop four alternative series for capital input that extend from 1889 to 2013, extending the data back from 1925 to 1889 through use of the estimates provided by Kendrick (1961). Figure A–1 shows each of these four series as an index number with 1928=100 to highlight differences among the four concepts between the 1920s and the 1950s. Because the differences among the series that matter for TFP are limited to the interval 1920–72, figure A-1 covers only those fifty-two years rather than the full 125 years for which each concept is calculated. In the subsequent sections, we indicate the sources for the data and the nature of the adjustments made to improve the measurement of capital input.

PRIVATE EQUIPMENT AND STRUCTURES

All data involving capital in this appendix and in chapter 16 have been recalculated to state real quantities in the fixed prices of 1950 rather than in the fixed

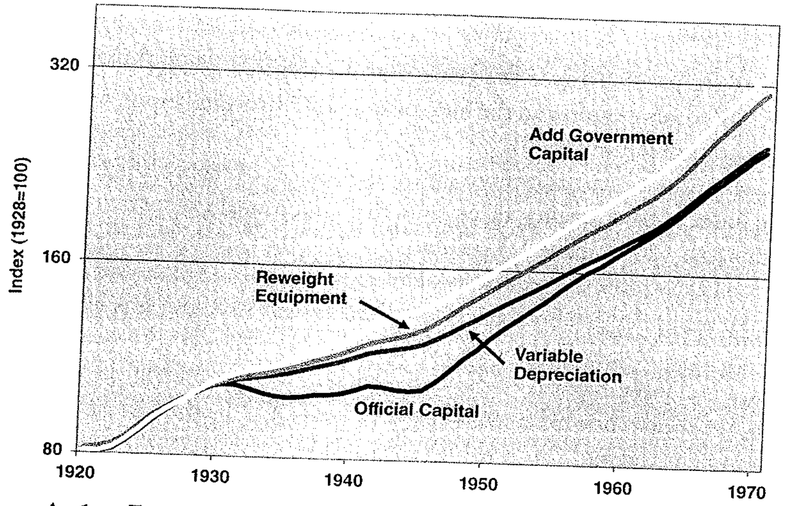

Figure A–1. Four Alternative Concepts of Fixed Residential and Nonresidential Capital Input, 1928=100, 1920–1970

prices of 2009 used in the published BEAFAA data. This eliminates changes in relative prices between 1950 and 2009 as a source of changes in such ratios as output to capital or government capital to private capital. This is appropriate, because the main focus of chapter 16 is on the change in the relationship between output and inputs between the 1920s and the 1950s, not between the 1950s and the recent decade.

Current cost estimates are taken from BEAFAA Table 2.1, lines 2 and 35. Quantity indexes are taken from the same lines of Table 2.2. Quantity indexes are multiplied by the 1950 current dollar value from Table 2.1 to create a constant dollar series in 1950 dollars, hereafter denoted $1950. The corresponding series for equipment and structures for 1889–1925 are taken from Kendrick (1961), Table A-XVI, columns 7 and 9, and are ratio-linked to the $1950 series at 1925.

The black line in figure A–1 exhibits the total of private equipment and structures as recorded in the BEAFAA. After a history of steady growth before 1929, this series stops growing between 1929 and 1944. The official series for private capital then turns sharply in 1945 from no growth to a rapid growth rate that continues throughout the postwar era. A fifteen-year hiatus in the growth of something as basic as the nation's capital stock raises red flags that something may be wrong, and it is. This leads us to make a transition to a new measure of capital input.[1] The differences between the various concepts help us understand the great leap of TFP between the 1920s and 1950s.

VARIABLE RETIREMENT

The BEA computes the capital stock by the standard "perpetual inventory" method. It starts with a value in the first year and then obtains the capital stock in the second year by adding gross investment in the second year and subtracting depreciation in that year. The key problem involves depreciation, which is based on a fixed numerical schedule that does not respond to current economic conditions. This assumption breaks down when there is a collapse of gross private investment, as occurred for most years between 1930 and 1945.

Buildings are normally torn down when profitability calculations suggest that there is a better use of the same plot of land. The official data assume that buildings constructed between 1880 and 1930 were torn down on a fixed schedule during the 1930s and early 1940s even though nothing was being built to replace them. Yet the streets of Manhattan in 1939 were not full of empty lots where pre-1930 buildings had been torn down. Instead, pre-1930 buildings remained in place throughout the 1930–45 period and helped produce output during those years.[2] The extent of the cessation of structures investment is summarized in the contrast of the ratio of gross investment in private structures to the capital stock of those structures—that ratio declined from an average of 4.8 percent during the years 1925–1929 to 1.1 percent in 1933 and did not exceed 4.0 percent until 1946. In fact, the average ratio of structures investment to structures capital in 1931–45 was only 39 percent of its average during 1925–29.[3]

A symbol of the hiatus in building construction, and with it building demolition, is provided by New York and Chicago. In New York, the tallest building was the Empire State Building, completed in 1931 and not surpassed until the World Trade Center was completed in 1974. In Chicago, the tallest building was the Board of Trade, completed in 1930, not surpassed until the construction of the Prudential Tower in 1957. In this long interval of minimal construction, buildings were not torn down, and hence the official BEA data overstate depreciation and understate the capital stock during the period 1930–45.

The same problem plagues the BEA data on producers' durable equipment. Though the productive lives of such assets are shorter, the phenomenon is the same.

When the Great Depression sharply reduced the ratio of gross equipment investment to equipment capital from 14.5 percent in 1929 to 6.5 percent in 1932, the pace of retirement of old equipment did not remain steady. The epochal achievement of the 1941–45 Arsenal of Democracy relied heavily on machinery that had been built in the 1920s and not retired "on schedule" during 1930–41. World War II has been called "the war of motors." The capacity of the American industrial establishment to build motors for trucks, tanks, and airplanes was vastly superior to that of any other country. In 1929, the United States produced 80 percent of the world's motor vehicles. Support for the view that retirement ages for equipment are extended during periods of weak investment comes from the machine tool industry. The percentage of American machine tools more than ten years old jumped from 46 percent in 1930 to 71 percent in 1940 and then declined to 42 percent as the stock of machine tools doubled during World War II (see below).[4]

The variable depreciation adjustment alters the BEA assumption of a fixed depreciation pattern to a variable depreciation pattern that equals BEA depreciation times the ratio of gross investment to the capital stock relative to its mean value. Thus, in 1933, when gross investment was low relative to the capital stock, depreciation was also low; similarly, in 1955, when gross investment was high, depreciation was also high.

The calculation begins with the series on current cost depreciation and a quantity index of depreciation from BEAFAA Tables 2.4 and 2.5, lines 2 and 35, which are combined to create depreciation of equipment and structures in constant 1950 dollars for 1925–2013. A series on gross investment of equipment and structures in constant 1950 dollars for 1901–2013 is created from BEAFAA Tables 2.7 and 2.8, lines 2 and 35. The ratio of gross investment to the capital stock (I/K) is then calculated, as is the mean of this ratio from 1925 to 1972. BEA depreciation is multiplied by an adjustment factor, which is the I/K ratio divided by its 1925–72 mean. Then the adjusted capital stock is calculated as a perpetual inventory using the new depreciation series in place of the official BEA depreciation series, using the standard formula $K_t = K_{t-1} + I_t - D^*_t$, where K is the capital stock, I is gross investment, and D* is the adjusted depreciation series. The adjustment is discontinued in 1964 when the adjusted capital series converges to the official BEA capital series.

Here is an example for the adjustment to equipment deprecation for the year 1933. The average investment-capital ratio for 1925–72 is 15.4 percent, but the actual ratio for 1933 is only 6.9 percent, or 0.45 of the average. This factor of 0.45 is multiplied by BEA depreciation of $12.7 billion (in 1950 dollars) for

an adjusted depreciation amount of $5.7 billion. Because depreciation is much lower than the BEA assumption that depreciation is unaffected by the slump of investment, the adjusted capital stock grows more rapidly than the BEA capital stock. Adjusted depreciation is less than BEA depreciation during 1930–44 except for the years 1937, 1940, and 1941 and greater than BEA depreciation in 1937, 1940–41, and 1945–63. For structures adjusted depreciation is less than BEA depreciation in 1930–45 and greater than BEA depreciation in 1945–63.

The result of the variable retirement calculation is shown by the dark gray line in figure A–1. Adjusted capital input grows faster than the official capital series during the years of low investment (1930–45) and more slowly thereafter. The variable retirement series converges to the official capital measure in 1964. The variable depreciation adjustment makes no difference for capital growth between 1929 and 1964 but plausibly rearranges the level and growth rates of capital input to correct for the BEA error in assuming fixed depreciation rates.[5] The new capital measure is identical to BEA capital for 1964–2013.

USER COST WEIGHTS FOR EQUIPMENT

The next adjustment recognizes the contribution of Jorgenson and Griliches (1967) and much subsequent research. Equipment investment is different than structures investment. The lifetime of equipment in service is much shorter than that of a structure. At one extreme, a laptop computer is replaced every three to five years. In the middle would be a tractor, truck, or car used for business that might be sent to the scrapyard after twelve to fifteen years. At the long end of longevity would be structures, many of which last for multiple decades and some for more than a century.

Many commercial buildings within the central parts of the nation's cities were built during the building boom of the 1920s and are now ninety years old. The core buildings in New York's Rockefeller Center are now eighty-five years old. Most residential structures last almost forever, and the topography of urban and suburban America allows the tracing of the transition from the Georgian townhouses of the early *nineteenth century* to the Queen Anne Victorians of 1880–1900 to tiny and forbidding Levittown structures of the early postwar years to the McMansions of today. Most residential construction has been on new sites, and relatively little has been torn down.[6] Structures last for a long time, but the life of equipment is shorter—and the implication of this leads inexorably to the conclusion that the "user cost" of equipment capital is much higher than for structures simply because equipment does not last as long and thus has a higher depreciation rate. Postwar data on capital input as compiled by the Bureau of Labor Statistics (BLS) weight equipment and structures by user cost, but these BLS data are not available for years before 1948. Because our major interest is in what happened between 1928 and 1948, we must develop our own user cost weights for the BEAFAA measures of equipment and structures.

The light gray series in figure A–1 shows that capital grows more rapidly when equipment and structures are weighted by user cost. The method allows for the shift within equipment capital from longer lived trucks and industrial machinery to short-lived computers and other electronic equipment. The multiplier on equipment relative to structures is calibrated to rise gradually from 3.0 in 1925 to 5.9 in 2013. The rate of change of this multiplier is adjusted so that the growth rate of the resulting capital input series is similar to the BLS series on fixed capital in the private sector. This adjustment matters more after 1972 than during the 1920–72 span of figure A–1.

GOVERNMENT CAPITAL

The final adjustment is for government capital, much of which consists of roads, highways, and other infrastructure that adds to productivity in the private sector, as well as government buildings and military facilities that contribute to the output of the government sector. The available data on government capital, however, must be treated carefully. Though all government structures provide a factor input to the total economy, the same is not true for the recorded totals of government equipment. Most government equipment in the BEA Fixed Assets accounts consists of military weapons, such as bombers, fighters, and naval combat vessels. These weapons do not produce output in the same sense as do nondefense government equipment and structures.[7]

The current-cost net stock of government assets comes from BEAFAA Tables 7.1A and 7.1B and includes line 3 for total structures, line 37 for federal nondefense equipment, and line 51 for state and local equipment. The real quantity indexes come from the same lines of Tables 7.2A and 7.2B and are converted into a real series in 1950 dollars. The white line in figure A–1 shows the effect of adding these components of government capital to the reweighted private capital stock. Government capital rises relative to private capital throughout the 1930s thanks to New Deal projects and highway construction and reaches its peak relative to private capital toward the end of World War II in 1944.

The role of government capital is shown in more detail in table A–1. Shown in the table are four categories of government structures—buildings, highways, military facilities, and other infrastructure (mainly dams and water/sewer projects). It is important to note that buildings include not just office buildings housing government workers, or schools for teachers and pupils, but also the substantial amount of "government-owned, privately operated" (GOPO) capital built as part of the effort to win World War II. When Henry Ford built a factory to assemble B-24 bombers, the cost of construction was not paid for by the Ford Motor Company, but rather by the U.S. federal government.[8] It was counted not as part of the capital stock in the private sector, but rather as part of the stock of government structures.

Table A–1 expresses each type of government structure assets as a percentage of private nonresidential structures assets, adjusted to incorporate variable depreciation.[9] This contrast shows how much government structures grew relative to private structures. By 1941, the ratio had already increased from 35.4 percent in 1928 to 58.0 percent and by 1944 had reached 68.6 percent, almost double the 1928 percentage. Somewhat surprisingly, the relative important of government to private structures did not decline after World War II. The total ratio shown on line (5) of table A–1 declines slightly between 1944 and 1950 from 68.6 percent to 66.1 percent and then increases further to 74.9 percent in 1957 and 93.4 percent in 1972.

The sources of these increases in the relative importance of government structures are subdivided among four categories shown in the first four lines of table A–1. Government buildings include all those buildings that house government employees, including state capitols, city halls, schools, state-owned colleges,

Table A–1. Government Structures as Percent of Private Nonresidential Structures, 1950 Dollars

	1928	1941	1944	1950	1957	1972	Change 1928-72
(1) Buildings	9.8	16.1	21.6	20.9	25.2	32.4	22.6
(2) Highways	12.7	20.1	19.2	19.1	22.2	31.6	18.8
(3) Military Facilities	4.1	5.6	11.9	10.9	11.2	8.9	4.8
(4) Other Infrastructure	8.2	14.8	16.5	15.1	16.2	21.2	12.9
(5) Total Government Structures	35.4	58.0	68.6	66.1	74.9	93.4	58.0

Table A–2. Percent Log Change from 1928 in Alternative Concepts of Capital Input

	1928	1941	1944	1950	1957	1972
(1) Official BEA Capital	0	4.2	2.6	22.2	47.1	99.7
(2) Variable Retirement	0	16.0	18.3	32.2	50.7	101.4
(3) Reweight Equipment	0	19.4	22.9	40.1	61.3	121.7
(4) Add Government Capital	0	25.1	30.9	46.3	68.3	128.0
(5) Full Adjustment, line (4)-(1)	0	20.9	28.9	24.0	21.2	28.3

facilities for police and fire protection, and prisons. Government highways are a large separate category. Military facilities include army bases, navy port facilities, naval bases, and training facilities. "Other infrastructure" includes "conservation and development" such as the building of levees or the maintenance of national and state parks, water supply facilities, sewage treatment facilities, and an "other" category. The Hoover Dam and the Tennessee Valley Authority (TVA) facilities, built in the 1930s, are examples of "other infrastructure."[10]

Table A-2 shows the percent log change from 1928 to five specified years of the four capital input series plotted in figure A–1, and several surprising results stand out. Of the total change between official and revised capital shown on line (5), most of the revision occurred between 1928 and 1941. The revised capital stock relative to 1928 is 25.1 percent higher in 1941 compared to only 4.2 percent for the official series, for a revision of 20.9 percent (25.1–4.2). Of this revision, more than half consists of introducing variable depreciation, which makes sense because gross investment was below normal more in the 1930s than in any other decade. The reweighting of equipment boosts the 1928–41 increase in capital by 3.4 percent and the addition of government capital by 5.7 percent.

The revision of 28.3 percent is identical in 1944 and 1972, but the composition of the revisions is very different. In 1944, the official capital measure is 2.6 percent above 1928, whereas the revised measure is 30.9 percent higher. Of that 28.3 percent difference, 15.7 percent is contributed by variable retirement, 4.6 percent by reweighting equipment, and the remaining 8.0 percent by adding government capital. Continuing past 1944, the contribution of variable depreciation gradually disappears through the mid-1960s, whereas the contribution of reweighting equipment becomes steadily more important as equipment investment grows relative to structures investment in the postwar years. Finally, the contribution of government capital, not surprisingly, peaks in 1944 but is still substantial in the other years shown.