Journal of Economic Perspectives—Volume 18, Number 2—Spring 2004—Pages 3–28

Distinguished Lecture on Economics in Government: Lessons from Past Productivity Booms

Roger W. Ferguson Jr. and William L. Wascher

The U.S. economy has been enjoying substantially faster productivity growth for the past eight years than it did over the preceding two decades. From 1995 to 2003, labor productivity rose at an average annual rate of about 3 percent, up from an average annual rate of around 1.5 percent between 1973 and 1995. In both 2002 and 2003, output per hour increased more than 4 percent. The significance of the improvement since 1995 can hardly be overstated, even after one takes into account the possibility that the increases of the past two years in part reflect cyclical influences and thus overstate the underlying trend. If productivity were to continue to rise at an average annual rate of 3 percent, the standard of living in the United States would double roughly every 24 years. If, on the other hand, productivity growth were to revert to an average annual pace of 1.5 percent, a doubling in the standard of living would occur every 47 years.

A number of observers argue that the present era of robust trend productivity growth will soon come to an end. Others contend that the potential gains to productivity from the technological advances associated with the computer revolution are far from complete.[1] In assessing the likelihood of these alternative outcomes, one should recognize that periods of strong trend productivity growth, although perhaps novel to many of us, are not new to the U.S. economy. In particular, three earlier periods of strong trend productivity growth stand out from

[1] For pessimistic views, see Baker (2002) and Madrick (2002). For more optimistic views, see Jorgenson, Ho, and Stiroh (2002) and Oliner and Sichel (2002). For a recent assessment of the new economy in this journal, see Baily's Distinguished Lecture on Economics in Government (Baily, 2002).

■ *Roger W. Ferguson Jr. is Vice Chairman and William L. Wascher is an Assistant Director in the Division of Research and Statistics, Board of Governors of the Federal Reserve System, Washington, D.C.*

the historical record as especially worthy of further scrutiny for the lessons they may offer regarding the current episode: the late 1800s from roughly the end of the Civil War to around 1890; the decade or so between the end of World War I and the onset of the Great Depression; and the period from about 1950 to the early 1970s.[2]

We will start by setting out some facts about these three previous periods of strong productivity growth in the United States. Each period can be associated with particular advances in technology, a connection implying that technological progress is a necessary component of trend productivity growth. But significant technological advances were also evident in periods when productivity growth was less robust. Thus, a natural question to ask is whether complementary factors—including aspects of the labor market, of the business environment or of government policies like those related to education—combine to render technological change especially potent or help to foster the transmission of technological change into real gains in the efficiency of the production process.

After touching briefly on possible reasons for the end of productivity booms, we will then turn to some of the lessons that can be learned from what, in many ways, are striking similarities across the three previous episodes and the current one. Those lessons suggest that government policies have only a limited role in these periods of elevated productivity growth. The larger share of the credit goes to the private sector, as private agents are generally responsible for creating and exploiting the technologies that drove these previous productivity booms. Nonetheless, governments can play an important subordinate role by supporting basic research and by fostering an economic environment that is conducive to private sector initiative.

Previous Productivity Booms by the Numbers

Basic facts about economic growth, not to mention the interpretation of those facts, are sometimes subject to considerable debate. Some of these disagreements result from the lack of consistent information on U.S. productivity before data from the Bureau of Labor Statistics (BLS) became available in 1948.[3] For this earlier period, we use data developed by John Kendrick (1961), who constructed estimates

[2] Others will undoubtedly disagree with this taxonomy. Gordon (2000a), for example, argues that the historical record of productivity growth in the United States is best seen as one big "wave" that begins its rise in the late 1800s and tapers off in the late 1960s and early 1970s. From a standpoint of technological advance, that characterization may be appropriate. But for assessing the diffusion of technology and the forces that contributed to the speed of the diffusion, a focus on narrower periods of labor productivity booms is arguably more relevant.

[3] Some analysts have also questioned whether the more recent estimates are overstating productivity gains, suggesting that these estimates do not accurately capture increases in hours worked away from the office made possible by the new information technologies. See, for example, Roach (2003). Freeman (2002) mentions this possibility, as well, but he and Gordon (2000b) also note that the availability of the Internet in the workplace may reduce productive work time in the office. To our knowledge, there are no statistical studies that net out these opposing effects.

of GDP going back to the 1870s that were consistent with the prevailing definitions in the National Income and Product Accounts and were, in turn, based on estimates made by Simon Kuznets (1946). These estimates are often cited as the best available measure of U.S. output and productivity growth for that period. Although subsequent researchers—notably Balke and Gordon (1989) and Romer (1989)—have refined these estimates, the additional refinements focus primarily on the cyclical properties of output. A number of economic historians have also estimated U.S. GDP for the period before the Civil War (Gallman, 1966; Rhode, 2002). However, given that these estimates are based on less reliable information than those for the later, more industrialized period, we have elected to focus primarily on the period after 1870.

Table 1 presents average growth rates of productivity over various periods from 1873–2003. The data for labor productivity—defined as output per hour worked in the nonfarm business sector—appear in the first column. The two remaining columns show a breakdown of labor productivity growth into the portion attributable to multifactor productivity (output per unit of labor and capital inputs) and the portion attributable both to capital deepening (capital services per hour multiplied by capital's share of current dollar costs) and the quality (education and work experience) of the workforce. As noted above, we focus mostly on the growth of labor productivity because of its relevance for improvements in the nation's average standard of living. However, the decomposition of labor productivity growth into its major components is also of interest because it provides information on the relative importance of technological progress and efficiency gains (which are included in multifactor productivity growth) versus the diffusion of technological change through investments in fixed and human capital.

For the total period from 1873 to 2003, labor productivity rose at an average rate of 2.2 percent per year, with both multifactor productivity and capital deepening contributing importantly to overall productivity growth. However, the increases in output per hour did not proceed in a steady fashion. Instead, periods of robust growth were interspersed with periods of more modest productivity gains. Recognizing that the choice of periods is subjective, we take as the first episode of strong productivity growth the period from 1873 to 1890. During this period, labor productivity rose 2.6 percent per year, a rate thought to be considerably higher than the average growth experienced over the first 100 years of the United States. Kendrick's (1961) decomposition suggests that labor productivity growth in the late 1800s was fueled in part by capital investment—as indicated by the 1.1 percent annual rate of increase in the last column of the table.[4] From 1890 to 1917, the growth rate of labor productivity slowed to an average pace of only 1.5 percent per

[4] This estimate of productivity growth is the change from Kendrick's estimate of the average level of productivity in the 1870s to the level of productivity in 1890. Decompositions of productivity growth before 1948 are the subject of some debate, and thus estimates of multifactor productivity for these earlier periods should probably be viewed as less reliable than are the estimates of labor productivity.

Table 1
U.S. Productivity Growth, 1873–2003
(average annual percent change, nonfarm business sector)

Period	*Labor productivity*	*Multifactor productivity*	*Contribution of capital deepening and labor composition*
1873–2003	2.2	1.3	.9
Episode I			
1873–1890	2.6	1.5	1.1
1890–1917	1.5	.8	.7
Episode II			
1917–1927	3.8	2.8	1.0
1927–1948	1.8	1.7	.1
Episode III			
1948–1973	2.9	1.9	1.0
1973–1995	1.4	.4	1.0
Episode IV			
1995–2003	3.0	1.0	1.6

Notes: Labor productivity is measured as output per hour worked in the nonfarm business sector. Multifactor productivity is defined as output per unit of combined labor and capital inputs. The contribution of capital deepening to labor productivity growth is the change in capital services per hour weighted by capital's share of nominal output, and the contribution from labor composition is the change in the average quality of the work force (by education and experience); separate estimates for capital deepening and labor composition are available only beginning in 1948. Data from 1873 to 1948 are taken from Kendrick (1961). For the periods after 1948, we use data from the U.S. Bureau of Labor Statistics. Labor productivity data from the BLS are available through 2003, whereas data on multifactor productivity, capital services and labor composition are published only through 2001.

year. The U.S. economy then enjoyed a relatively brief spurt in labor productivity until about 1927, with labor productivity rising 3.8 percent per year and multifactor productivity up 2.8 percent per year. This productivity boom was led by the expansion of the automobile industry and robust productivity gains in manufacturing more generally. Productivity growth was markedly slower during the period that included the Great Depression and World War II (from 1927 to 1948), largely because of a lack of capital deepening. Multifactor productivity rose at a relatively solid pace—albeit not as fast as earlier in the century—despite the weak economy during much of that period.

From 1948 to 1973, a period sometimes referred to as the golden age of productivity growth, labor productivity rose at an annual rate of close to 3 percent. During this period, productivity accelerated across a broad range of industries, and both capital deepening and gains in multifactor productivity contributed to the strong pace of growth. During the productivity slowdown of the 1970s and 1980s, labor productivity growth slowed to an average pace of 1.4 percent per year, while multifactor productivity growth fell to a pace of 0.4 percent, the slowest pace of any of the periods shown in the table. Finally, labor productivity growth averaged 3.0 percent at an annual rate from 1995 to 2003, with higher rates of both capital deepening and multifactor productivity growth contributing to the pickup.

Sources of Past Productivity Booms: Technological Change

Although the productivity booms of the past century and a quarter obviously differed in many respects, each episode can readily be associated with the introduction of one or more prominent new technologies.

The productivity boom after the Civil War, for instance, appears to have had its genesis in a set of technological improvements that increased the flexibility of production and reduced transportation costs, which allowed firms to take advantage of economies of scale in production and distribution. The widespread introduction of steam engines and machinery powered by coal enabled firms to move away from sources of water power and closer to areas where inputs of labor and raw materials were more readily available. The Midwest—where water power was less abundant but coal was more abundant—benefited greatly from this development and, indeed, within a few decades became known as the "industrial heartland" of the United States. As a result of this regional shift in economic activity, the share of personal income generated in the Midwest rose from 20 percent in 1840 to 35 percent in 1880, whereas the share of income generated in the Northeast declined from 43 percent to 31 percent over that period (Easterlin, 1961).

The expansion of railroad transportation also helped raise productivity growth in the second half of the nineteenth century. Improved methods of steel production—notably, the Bessemer process and, later, Siemens's open hearth method—enabled railroads to lay longer-lasting steel track rather than iron track. The growth of telegraphy enabled railroad companies to coordinate the movement of trains over a wider area. As a result, railroads expanded their geographic coverage significantly after the Civil War. From 1860 to 1890, the number of main track miles operated by railroad companies more than quintupled, from 31,000 miles to 167,000 miles, while the number of freight cars in operation jumped from 185,000 to more than 1 million (U.S. Census Bureau, 1997, Series Q321; Fishlow, 1966).

Although the magnitude of the railroad's contribution to productivity growth during this period is the subject of considerable debate (David, 1969; Fishlow, 2000; Fogel, 1979), the expansion of the railroads clearly drove transportation costs sharply lower and resulted in significant increases in the geographic size of product markets. In 1830, the transportation of goods from New York to Chicago occurred mainly by canal and required three weeks even during the warmer months of the year; moreover, canals often did not operate in the winter. In contrast, by 1870 the same goods could be transported between these two cities in three days by railroad any time of the year (Paullin, 1932). In addition, the construction of new rail lines in western states opened those markets to a wide range of east coast and midwestern manufacturers. Subsequently, freight rates fell from $2\frac{1}{4}$ cents per ton-mile in 1860 to less than 1 cent per ton-mile by 1890. As a result, the quantity of goods transported by rail increased sharply, from about 12 billion ton-miles in 1870 to 80 billion ton-miles in 1890.[5]

The advances in transportation were complemented by improved communications, largely as a result of the expansion of the telegraph. As noted above, the telegraph aided the expansion of railroads by improving the coordination of rail traffic. But the ability to send messages rapidly over long distances also proved valuable in many other industries. Initially, sending a telegram was relatively expensive, with rates between New York and San Francisco averaging $7.45 for ten words or less in the late 1860s. By the late 1880s, rates for the same message had fallen to as little as $1.00. As a result, the number of telegraph messages handled by Western Union rose from less than 6 million in 1867 to nearly 56 million in 1890 (U.S. Census Bureau, 1997, Series R48 and R74). The better information flows that accompanied the wider use of telegraphy contributed to better decision making and higher productivity throughout the economy.

Agriculture also was increasingly mechanized in the decades immediately after the Civil War, though the change in agriculture was not as impressive as in the industrial sector. The abundance of land in western states limited the interest among farmers in raising land productivity. However, labor services were often difficult to obtain, so farmers were quite willing to invest in labor-saving machinery. As a result, the better plows, seed drills, reapers and threshers developed by manufacturers were in high demand by farmers, and the amount of labor required to farm an acre of land fell sharply for many crops (Atack, Bateman and Parker, 2000).

In the second productivity boom in the years after World War I, the chief technological innovation was most likely the spread of electrification to the factory floor. The use of electric motors in the production process increased substantially in the first quarter of the century (David, 1990; Mowery and Rosenberg, 2000). For example, the amount of mechanical energy derived from electric motors rose from 475,000 horsepower in 1899 to nearly 34 million horsepower in 1929, and the fraction of overall factory horsepower produced with electricity rose from less than 5 percent to more than 80 percent over that period (U.S. Census Bureau, 1997, Series P70). With electric motors, each machine in a factory could be driven by its own power source. As a result, manufacturing plants could be organized in a way that maximized the efficient movement of materials, rather than the efficient transmission of power. In this regard, electric motors facilitated the spread of

[5] Estimates of track construction, freight rates and ton-miles transported are taken from Fishlow (1966, 2000).

continuous processing techniques and assembly lines. As firms moved to reorganize their production processes to take advantage of the increases in efficiency afforded by electric power, factory productivity rose significantly. By one estimate, productivity growth in the manufacturing sector as a whole increased about $5\frac{1}{2}$ percent per year between 1919 and 1929 (Kendrick, 1961, p. 152).

Of course, other technological innovations also contributed to productivity growth during this period. Notable among them were the telephone, which by the 1920s had largely replaced the telegraph; the internal combustion engine, which led to motorized vehicles that brought sizable productivity gains in the transportation and agriculture sectors; and a variety of technological advances in machine tools. In addition, the early 1900s were characterized by the first wave of office automation equipment, including the portable typewriter and adding and duplicating machines. These machines improved the efficiency of a wide range of management and accounting tasks. In real terms, business investment in office equipment increased from about \$50 million (in 1929 dollars) in 1899 to nearly \$500 million in 1929, with a particularly large jump evident in the 1920s (Cortada, 1993, Figure 3.1).

The productivity gains of the 1950s and 1960s had their roots in a wide range of technological innovations made during the 1930s as well as in research sponsored by the military during World War II. Field (2003), in particular, emphasizes the importance of technological change in the 1930s and points to the array of process and product innovations compiled by Kleinknecht (1987), Schmookler (1966) and Mensch (1979) as evidence.[6] Examples of important innovations during this decade include research advances in polymer chemistry that led to the invention of Plexiglas, Teflon and Nylon; significant advances in civil engineering; and the introduction of the DC-3 aircraft in 1936.

Research aimed at enhancing U.S. military capabilities during World War II also led to new technologies that had important spillovers to commercial applications after the war (Mowery and Rosenberg, 2000). For example, although the major research advances in synthetic polymerization chemistry (most notably, the introduction of catalytic cracking in the processing of crude oil) were made in the 1920s and 1930s, the synthetic rubber program launched during the war resulted in techniques that led to the mass production of the first synthetic polymer from petroleum-based feedstocks. Similarly, production of polyethylene, a petrochemical-based plastic discovered in the 1930s, jumped in the 1940s because of its widespread use in military equipment. The military's need for large stocks of penicillin led to a production process for it that turned out to have applicability to a wide

[6] Field also points to the sizable increase in multifactor productivity between 1929 and 1941 as evidence of the extent of technological progress during the 1930s. As he notes, however, Goldin (2000) and Bernanke and Parkinson (1991) offer alternative explanations for the rise in productivity over that decade.

range of pharmaceuticals, while wartime advances in microelectronics subsequently contributed significantly to the development of new commercial electronic products.

The commercialization of these earlier innovations sharply increased the number of products made wholly or partly from newly developed plastic polymers and other synthetic materials. The use of polyethylene, for example, spread quickly after the war, and additional technological advances isolated new forms of synthetics and further reduced production costs for chemicals and pharmaceuticals. Overall, between 1947 and 1970, production in the rubber and plastic products industry rose nearly 7 percent per year, and the output of the chemical products industry rose more than 8 percent per year (Board of Governors of the Federal Reserve System, *Indexes of Industrial Production*). In comparison, over the same period, production in the manufacturing sector as a whole rose about $4\frac{1}{2}$ percent per year.

Other notable contributors to productivity growth during this period include the invention of the transistor in 1947 and the diffusion of earlier technological advances into the transportation sector. Commercial applications of the transistor, initially in solid state consumer electronic products, were stimulated by improvements in the fabrication process (in 1954) and by the introduction of the integrated circuit (in 1958). With the rise in demand, semiconductor production jumped markedly, rising nearly 20 percent per year during the 1960s (Board of Governors of the Federal Reserve System, *Indexes of Industrial Production*).

In transportation, the 1950s and 1960s saw major productivity improvements in all three major segments: air, rail and trucking. Gordon (1992) estimates that labor productivity in the railroad industry rose at an average annual rate of around $4\frac{1}{2}$ percent between 1948 and 1969; contributing importantly to those productivity gains were the replacement of steam locomotives with diesel locomotives and innovations that increased the capacity of the rolling stock (Mansfield, 1965). The use of the jet engine in commercial aircraft—most notably, the introduction of the Boeing 707 in 1958—sharply reduced the time and cost of transporting passengers and freight, and Gordon's estimates place the growth of productivity in the commercial airline industry at more than 7 percent per year during the 1960s, well above the rate of labor productivity growth for the economy as a whole.[7] Finally, while technological improvements in internal combustion engines also found their way into medium and heavy trucks during this period, productivity gains in trucking—estimated by Gordon at about $3\frac{1}{2}$ percent per year in the 1950s and 1960s—were fueled importantly by substantial investment in road improvements,

[7] Of course, the invention and commercial use of the airplane was a technological innovation that predated the jet engine, and air travel in the late 1920s represented a substantial improvement over other forms of passenger transportation. The estimates of Gordon (1992) show that productivity in airline transportation rose about 7 percent per year between 1935 and 1959, as well.

most notably the federally funded expansion of the U.S. highway system (Keeler and Ying, 1988).

For purposes of comparison, the technological origins of the more recent productivity boom also bear a brief mention. Obviously, the invention of the transistor and the development of the mainframe computer were precursors of the technological advances that contributed to the current productivity boom. However, the real drivers of the productivity gains in the 1990s were the related high-tech innovations of the 1970s and 1980s, including the personal computer, fiber optics, wireless communications and the Internet. Many of the recent technological innovations have significantly altered the ways in which firms interact with their customers and have raised the productivity of the economy as a result (Brynjolfsson and Hitt, 2000). Nearly all large retail chains have followed the lead of Amazon.com and established an on-line presence; customers now routinely pay bills online; and computerized reservations and e-tickets have become the norm in the travel industry. Moreover, from manufacturing to retailing, innovations in supply-chain management practices made possible by new technologies have substantially reduced inventory-related costs.

Sources of Past Productivity Booms: Organizational Change

In most cases, the principal technologies that stimulated past productivity booms were invented well before the productivity gains were realized. For example, the steam engine was invented in the 1700s, well before it had any measurable effect on the production process in the United States. Similarly, railroads were being built in the 1840s, and the first electric power plant was built in 1882. Computers were introduced in 1945, and the absence of a measurable contribution to productivity was a puzzle to many economists as late as the mid-1990s (Oliner and Sichel, 1994). What delayed the translation of these innovations into gains in productivity? In part, the lags reflected the challenges of developing commercial applications for the new technologies; for example, complementary innovations were frequently required to enable new inventions to be put to practical use. In addition, replacing older machines with equipment that embodied the new technologies was often not immediately profitable, and thus, firms frequently took some time before making the capital investments required to take full advantage of technological progress.

However, substantial changes in business practices and in the organization of firms often were also needed to enable businesses to achieve the potential productivity gains associated with new technologies. In many cases, these organizational changes went hand in hand with the technological advances—the changes both being made possible by the new technologies and being necessary to achieve the additional productivity associated with the use of these technologies. Chandler

(1977), in particular, documents the evolution of the modern business enterprise, pointing out both how new technologies influenced the optimal hierarchical structure of the firm and how the resulting changes in business organization increased productivity.

In the productivity boom of the late nineteenth century, the major organizational changes involved firms growing in size to take advantage of the economies of scale made possible by the new technologies. Before the Civil War, most businesses were either sole proprietorships or partnerships serving local markets, and they consisted of small shops that employed skilled workers involved in each aspect of the production process. As the spread of railroads lowered transportation costs and increased the size and number of potential markets, the greater availability of steam power enabled manufacturers to set up factories to take advantage of economies of scale in production. As a result, the size of firms rose substantially in many industries. In the cotton industry, for example, the median firm size (measured as the annual value of gross production in 1860 dollars) rose from $31,000 in 1850 to nearly $100,000 in 1870; similarly, in the iron industry, the median firm size rose from $24,000 in 1850 to more than $200,000 in 1870 (Atack, 1986). Outside manufacturing, the emergence of large wholesalers (and, later, retailers) to take advantage of increased distributional efficiencies reduced the costs of moving commodities and manufactured goods from the farm or factory to retailers' shelves.

These larger enterprises had to confront communications challenges in both production and distribution. With the telegraph making rapid communication over great distances more feasible, firms were able to monitor activities from a central administrative office. However, processing the increased flow of information required changes in the organizational structure of the firm. In particular, to make effective use of the opportunities presented by better communications, firms often set up hierarchical management systems to control the production process and to coordinate the flow of goods across the distribution system. The more informed decision making associated with this administrative structure enabled firms to match production to orders, shorten delivery times and reduce inventory holdings.

The second major productivity boom, in the years after World War I, required changes in business organization that permitted firms to take advantage of advances in production processes in the early 1900s. These changes involved both the economies of scale associated with the increasingly complex production techniques in the manufacture of goods and also large organizations embracing economies of scope. The diffusion of the electric motor throughout the factory floor increased the use of continuous-process methods and the assembly line and, thus, accelerated the trend toward mass production. In addition, as early as the 1880s, manufacturers had begun to integrate forward into distribution; one noteworthy example was the meatpacking industry, in which firms purchased refrigerated rail cars that allowed the shipment of beef from centralized slaughterhouses to branch houses that served local markets. The advances in mass production techniques and the increasing complexity of many manufactured products led firms in other industries to integrate forward not only into distribution but also into retailing; this vertical integration reduced transactions costs even more and further increased the optimal size of firms. Many of the large corporations that arose at this time—Ford, General Motors and General Electric, for example—are still with us today.

The vertical integration of these large corporations, in turn, led to a greater emphasis on retail, accounting, advertising and other activities not directly related to production (Galambos, 2000). To compete in retail markets, firms needed to understand the latest consumer trends and to encourage consumers to associate specific products with a particular firm; in addition, firms needed to establish accounting systems to keep track of a wider range of activities. As a result, marketing, advertising and accounting departments increased in size and importance within the typical corporation. Also, with their executives now more sensitive to market share and their cost advantage over their competitors, large corporations began to develop applied research departments aimed at providing the firm with a technological edge.

During the third productivity boom, following World War II, firms responded to the myriad of new products made possible by the technological advances of the 1930s and 1940s by making new changes in their organizational structure. In particular, corporate managers increasingly split their firm's activities into separate divisions, each with its own manufacturing and marketing departments. For domestic production, this multidivisional approach was well-suited to the manufacturing of diverse product lines by a single company; DuPont and Monsanto are good examples of this approach (Baskin and Miranti, 1997). This structure also turned out to be an effective method of handling corporate operations in different geographic areas, as seen by the rise of multinational corporations during this period. After World War II, new trade agreements and efforts to revitalize Europe and Japan allowed American firms to make significant inroads into foreign markets. To handle these long-distance operations more easily, corporations often set up foreign subsidiaries that could adapt quickly to changing circumstances in the host country's marketplace. The economic importance of these multinational corporations rose steadily, so that by 1966, the total assets of U.S. multinational firms accounted for nearly 35 percent of U.S. corporate assets (U.S. Bureau of Economic Analysis, 1966).

Organizational structure during the productivity boom of the late 1990s has, in some respects, shifted away from the large corporations that dominated the U.S. economy during much of the twentieth century. To be sure, the marketplace in many industries is still characterized by large, well-established firms. In some industries—the financial services sector comes to mind—recent technological innovations have, if anything, increased the scale of business. But in other industries, intense global competition has motivated many corporations to narrow their focus to core production-related activities and to outsource other functions. Increasingly, these supporting firms are providing their services from overseas, taking advantage both of lower labor costs there and of the revolution in communications. The impact of this outsourcing is already evident in the business community, with some computer-related support for U.S. providers located in India, architectural drawings rendered in the Philippines and some legal functions provided from nations in the Caribbean.

In addition, much of the rapid technological innovation since 1995 or so has occurred outside the large corporate sector, and the success of that innovation has boosted the pace at which new ventures are being created. For example, more than 700,000 new businesses were incorporated each year, on average, in the 1990s, about double the pace of the 1970s (U.S. Census Bureau, 2001). Of course, many of these firms failed. However, many others either grew or were bought by larger firms better able to market and distribute the most promising innovations.

Sources of Past Productivity Booms: Financial Market Change

A third major ingredient in promoting the productivity gains associated with technological innovation has been a complementary set of innovations in the financial sector that have changed the financial landscape in ways that were especially appropriate to the predominant form of business organization in each period.[8]

Before the Civil War, most nonfinancial business investment was financed internally with retained earnings, with capital provided by family or friends or through partnerships formed with other proprietors. The chief exceptions were the canals and railroads, which were issuing stocks and bonds in the 1850s (Chandler, 1977). With the sharp increases in the scale of operations of many firms after the Civil War, however, businesses in other industries perceived a need for greater capital investments and began to look more toward external sources of financing.

The main sources of funding in the decades after the Civil War were debt and preferred stock—that is, stock that promised a certain dividend but had no voting rights. (Railroad companies were an exception to this pattern—they sold sizable amounts of common stock to investors seeking large capital gains after the completion of new construction projects (Fishlow, 2000).) Debt often took the form of secured loans, in large part because investors were concerned about the informational asymmetries they faced in evaluating the bankruptcy risk of particular firms. In addition, the owners of many firms preferred financing with debt rather than common stock because they did not want to see their equity diluted or their control of the enterprise diminished. Similarly, preferred stock, which reduced bankruptcy risk but did not dilute the owners' equity in the firm because it offered no voting rights, was often used when assets were insufficient to secure the loan. Thus, despite the prevalence of information problems, financial intermediaries were able to

[8] This section draws from Baskin and Miranti (1997) and White (2000).

provide firms with external sources of funds, making possible the rapid buildup in the capital stock that took place in the late 1800s. Indeed, the total value of bank loans rose from less than $1 billion in 1870 to more than $4 billion in the early 1890s, a notable increase in nominal value during a period when the aggregate price level was falling (U.S. Census Bureau, 1997, Series X581).

Corporate finance in the years after World War I was characterized by an increase in the importance of equity markets. At the New York Stock Exchange alone, the volume of stock sales rose from 186 million shares in 1917 to more than 1 billion shares in 1929 (U.S. Census Bureau, 1997, Series X531), the value of preferred and common stock issuance increased from $455 million to $6.8 billion over the same period (U.S. Census Bureau, 1997, Series X514-515), and the number of individuals holding stock jumped from 500,000 in 1900 to 10 million by 1930 (Hawkins, 1963).

The public's interest in common stock increased for several reasons. First, and probably most important, the profitability of large corporations during the early 1900s was accompanied by expanding middle and upper classes that wanted to take part in the economic gains associated with the introduction of new technologies such as the internal combustion engine and the electric motor. The main way to share in these capital gains was to purchase some ownership in those corporations. About the same time, the informational problems that had constrained interest in common stock through the early 1900s were declining. Rising demand from investors in the late 1800s for information about railroad companies had led to the proliferation of newsletters that reported on developments in that industry, and similar publications soon sprang up to provide information on other traded securities. These newsletters evolved into ratings agencies covering a wide range of individual corporations, with Moody's issuing the first bond ratings in 1909. Although these agencies' ratings focused on corporate bond issues, many also provided economic forecasting services and more detailed information about the relative risk of specific companies. As a result, more public companies recognized a need to address investors' concerns about risk and began to issue regular audited financial statements (Miranti, 2001). Interest in common stock was also fueled by the tendency to imbue them with characteristics similar to those associated with debt, with which investors were more familiar. For example, businesses frequently attempted to establish steady dividend streams in order to boost investors' confidence about the future profitability of the firm and to encourage them to hold their securities (Baskin and Miranti, 1997). Finally, the marketing of securities to the household sector became more aggressive in the 1920s, led by investment trusts—which offered investors a means of diversifying individual portfolios—and retail brokerage firms.

The third productivity boom, in the years after World War II, was accompanied by another rapid increase in bond and equity issuance. Despite significant increases in internal funds, the growth of investment spending over this period outpaced the rise in retained earnings, and the ratio of external financing to overall capital spending rose from an average of around 30 percent in the late 1940s to more than 40 percent in the early 1970s (Board of Governors of the Federal Reserve System, *Flow of Funds Accounts*).

Two specific developments in financial markets during this period bear mentioning. First, the late 1950s and 1960s saw the rise of the Eurodollar market—a market for U.S. dollar deposits and loans outside the United States and, at least initially, in Europe. Although the origin and early development of the Eurodollar market is attributed, in part, to a desire by holders of dollars to avoid U.S. regulations, including the Regulation Q interest rate ceilings, that market subsequently became a useful source of short-term financing—complementary to the commercial paper market—for large corporations seeking alternatives to more costly domestic commercial bank loans (Johnston, 1982; Kindleberger, 1993). Although no direct data on the size of the Eurodollar market are available, Baskin and Miranti (1997) estimate that this market increased from about $9 billion in 1964 to $247 billion by 1976. Second, the 1950s and 1960s were characterized by a sharp rise in the importance of large institutional investors—especially pension funds—in the stock and bond markets. This rise, coupled with the growth of mutual funds and brokerage houses, enabled smaller investors (either explicitly or implicitly) to invest more easily in stocks and bonds and to diversify their portfolios.

In the most recent productivity boom, financial intermediaries have expanded the range of financing alternatives available to businesses in response to the proliferation of start-up businesses and what is, for many firms, a riskier business environment. For larger lower-rated corporations that have significant default risk, the so-called junk bond market has offered the capability to raise funds even when other sources of financing are less available. Such firms' use of this market has increased markedly: Junk bond issuance rose from about $11 billion in 1984 to more than $100 billion in 2001, and the par value of outstanding junk-rated debt has increased from less than $100 billion in the mid-1980s to nearly $700 billion today. For smaller and yet-riskier firms, venture capital and initial public offerings have been important sources of financing. Venture capital investments, which were negligible in the early 1980s, rose to more than $100 billion in 2000, although they have since dropped back. Similarly, initial public offerings for nonfinancial companies (excluding spinoffs and leveraged buyouts) exploded from less than $5 billion per year in the late 1980s to roughly $30 billion in 2000.[9]

In addition, the financial industry has made significant advances in quantifying and managing risk. Many large financial institutions have, over the past decade, increasingly adopted internal credit-risk models to improve their ability to assess the riskiness of their portfolios. Moreover, financial market innovations, including

[9] Data on junk bonds in this paragraph are from Thompson Financial Securities Data Corporation and Moody's Investors Service. Data on venture capital investments are from PricewaterhouseCoopers/Thomson Venture Economics/National Venture Capital Association, *MoneyTree Survey*. Data on initial public offerings are from Thompson Financial Securities Data Corporation.

securitizations, credit derivatives and an improved secondary loan market, have allowed these institutions to manage their exposure to such risks better. These improvements in risk management may help to explain why financial institutions weathered the 2001 economic downturn so well relative to their difficulties in previous recessions.

Sources of Past Productivity Booms: Human Capital Accumulation

A fourth ingredient contributing to the productivity booms of the past has been the availability of a workforce capable of bringing to fruition the possibilities opened up by the technological innovations. In the 1800s, the new manufacturing technologies tended to be complementary with unskilled labor, whereas those associated with the distribution of goods tended to require more-skilled workers. In contrast, in the 1900s, technological change tended to increase the demand for skilled workers in both sectors. These shifts in labor demand typically were manifest in changing wage premiums for skilled labor, and workers responded to the incentives in ways that generally provided employers with a mix of workers able to harness the productivity improvements associated with the new technologies.

During the productivity boom in the late nineteenth century, technological change had two disparate effects on the demand for labor. First, the shift in manufacturing production from artisanal shops in the mid-1800s to factories after the Civil War and the subsequent rapid growth in the capital stock led to a substantial increase in the demand for unskilled labor (Engerman and Sokoloff, 2000). The new capital equipment embodying the technological advances of that period, coupled with the use of unskilled labor and the abundance of raw materials, often proved to be an effective substitute for skilled artisans (James and Skinner, 1985), and so firms increasingly looked to hire workers without any specific expertise to operate the new machines. Although such workers—who were often women, children and immigrants—likely reduced the average skill level of the manufacturing workforce, the availability of a large pool of unskilled labor enabled firms to take advantage of the potential organizational efficiencies and economies of scale associated with the new technologies, thus raising productivity for the economy as a whole.

Second, increases in firm size and the growth of businesses in the distribution sector increased the demand for workers who could perform clerical and managerial tasks. For example, the share of employed men who worked in white-collar occupations rose from less than 5 percent in 1850 to nearly 18 percent by 1900 (Margo, 2000). As these jobs typically involved some basic knowledge of reading and mathematics, such workers tended to have more formal education than the average individual. However, the level of competency needed for these jobs generally consisted of bookkeeping and secretarial skills that required, at most, a high school education (Chandler, 1977).

On net, these influences seems to have led to only a slight increase in the wage premium for skilled labor during the 1870 to 1890 period (Margo, 2000), and as a result, there was little impetus for widespread increases in educational attainment among the U.S. population. School enrollment rates among children held steady at about 50 percent over that period, and high-school graduation rates remained below 5 percent (U.S. Census Bureau, 1997, Series H433, H599).

The productivity boom of the early twentieth century was accompanied by a significant rise in the demand for higher-skilled labor. The need for white-collar workers continued to increase with the further growth in corporate size and the new focus on activities not directly related to the manufacture of goods. Moreover, these additional activities required better-educated managers to control and coordinate the diverse functions of the corporation and more-skilled clerical workers to process the increased flow of information associated with vertical integration. The acquisition of these additional skills took place in different ways. Chandler (1977) emphasizes, for example, the inception of the modern business school during this period, with classes on commerce, accounting, marketing, law and finance. Cortada (1993) notes also that vendors of new office machinery often educated clerical workers about the uses and operation of the new equipment.

In contrast to the late 1800s, the use of more-advanced technologies in the manufacturing sector also led to a relative shift in labor demand toward more capable and highly educated blue-collar workers. In particular, the increasing use of continuous processing production techniques made possible by the electrification of factories reduced the demand for unskilled manual workers, while the greater complexity of the newly installed capital equipment increased the demand for workers who could read manuals and blueprints, perform mathematical calculations requiring knowledge of algebra and geometry and had some basic knowledge of science (Goldin and Katz, 1998). In response, enrollment rates in secondary schools increased sharply, and the high school graduation rate rose to more than 25 percent by the late 1920s (U.S. Census Bureau, 1997, Series H599).

The productivity boom of the 1950s and 1960s showed a similar pattern. The new technologies and skilled labor again were complements in production, so that the availability of skilled labor in this episode helped to maintain the returns to technological innovation. As in the early 1900s, the greater cognitive skills possessed by more-educated workers were especially effective in implementing the new technologies (Nelson, Peck and Kalachek, 1967), and in this instance, the demand for workers in professional and technical occupations increased sharply, with especially rapid growth for engineers and technicians (U.S. Census Bureau, 1997, Series D233-D682). With the occupations in highest demand now requiring a college education, the percentage of 18- to 24-year-olds enrolled in college rose from about 14 percent in 1950 to roughly 32 percent in 1970 (U.S. Census Bureau, 1997, Series H701).[10]

The current productivity boom has also been characterized by skill-biased technological change, with the advances in the high-tech sector associated with a sharp increase in the demand for workers with computer-related skills and a further widening in the skill premium for workers with a college degree. As a result, college enrollment rates, which stagnated during the productivity slowdown in the 1970s and 1980s, began to rise again in the 1990s. In addition, the demand for lower-skilled workers has been damped in recent years by the longer-term downtrend in large segments of the manufacturing sector and competitive pressures more generally (Paul and Siegel, 2001). In response, many lesser-skilled adults have moved to retool their skills by returning to school (Kane and Rouse, 1999). Most notably, enrollments at community colleges increased about 30 percent between 1985 and 2000, and the percentage of adults attending an education program rose from 33 percent in 1991 to 45 percent in 1999, with a particularly large increase evident for the unemployed.[11]

Why Do Productivity Booms End?

It is informative not only to identify the sources of past productivity booms, but perhaps also to ask why periods of strong trend productivity growth end. Three possibly overlapping hypotheses have been put forth. First, successful new technologies may eventually lead to financial imbalances and overinvestment associated with excessive optimism. Second, periods of strong productivity growth may eventually run out of steam as the productivity-increasing opportunities associated with new technologies are exhausted. Third, exogenous shocks may bring an end to boom periods. Although elements of these three hypotheses can be seen in the past episodes of productivity booms, no clear pattern emerges.[12]

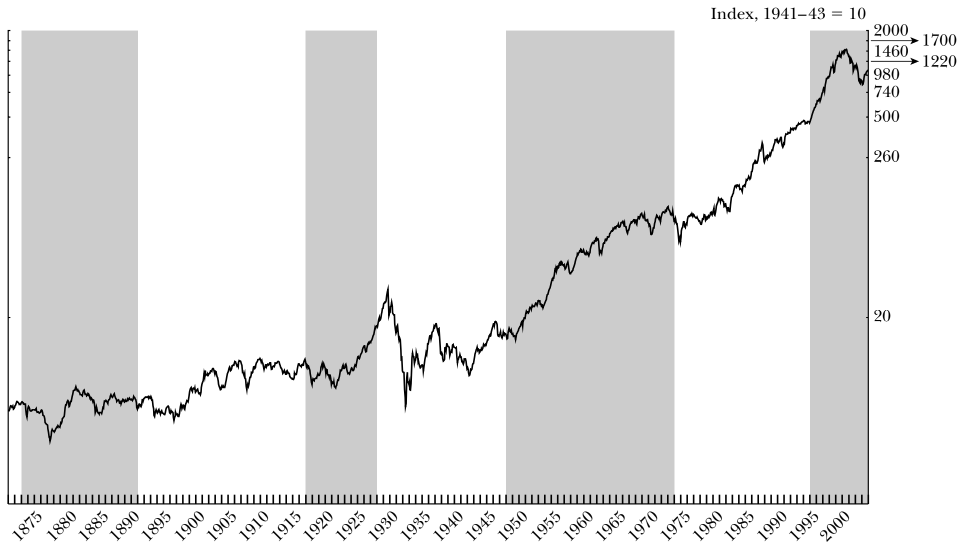
Some support for the hypothesis that financial imbalances may end productivity booms can be seen in Figure 1. Each of the episodes discussed in this paper

[10] The increase in college enrollments during this period was likely also boosted by the use of college deferments during the Vietnam War and by the G.I. bill.

[11] U.S. Department of Education, *Digest of Education Statistics*. Owing to data limitations, this measure includes adults enrolled in personal development programs. In 1999, for which more detailed information is available, roughly one-third of adults were participating in postsecondary education or career-related courses.

[12] We also note that each of the productivity booms we have discussed ended with a severe recession. However, this fact is a feature more of the way we identified the episodes of rapid productivity growth than of the episodes. In particular, we chose to measure our productivity booms between years in which cyclical conditions were roughly comparable precisely because we wanted to avoid contaminating our estimates of longer-run productivity growth with the sharp cyclical decline in productivity that typically accompanies a recession.

Figure 1
S&P Stock Price Index



included a period of soaring stock prices: in the late 1870s, the 1920s, the 1960s and the late 1990s. In the late 1920s, the end of the run-up in equity prices was followed by a stock market crash; in the other three cases, after the run-up, stock prices fell substantially, but these declines could perhaps be considered "corrections" rather than "crashes." Did these stock market booms and falls reflect an overbuilding of investment capacity? By the end of the 1920s, certain industries—most notably automobiles and electric utilities—arguably had experienced a significant overbuilding of capacity. Similarly, in the late 1990s, there does appear to have been an overinvestment in high-tech and telecommunications equipment. But evidence of overinvestment is much harder to find in the late 1800s and in the 1960s. Indeed, one can even argue that the decline in stock prices in the mid-1970s was due largely to the beginning of a recession and the failure of economic policy to control inflation rather than to excessive optimism. Moreover, although the stock market declines of the 1880s and 1920s were both followed by extended economic depressions, modern economic analysis stresses that serious monetary policy mistakes were necessary for these depressions to occur (Rockoff, 2000; Bernanke, 1995). Also, although there likely was overinvestment in the high-tech sector in the late 1990s, the recent productivity data do not suggest that the current productivity boom has ended.

The second hypothesis—that productivity booms end when innovation and technical change levels off—surfaced to explain the productivity slowdown of the 1970s, with proponents pointing to a deceleration in the growth of research and development spending in the late 1960s as evidence of a decline in innovation.

Griliches (1988) has argued convincingly that this shortfall in R&D spending was not of sufficient magnitude to contribute much to that productivity slowdown, and the absence of data on R&D spending in earlier periods makes this hypothesis difficult to evaluate more generally. However, even if technological advances are eventually exhausted, we have no evidence that this possibility is as yet a significant risk to the current productivity boom. Both industrial R&D and patent applications have risen rapidly in recent years, suggesting that innovation—and the potential productivity gains associated with technological progress—will likely remain an important source of economic growth in the United States in coming years.

The third hypothesis—that exogenous shocks may contribute to the end of productivity booms—is also evident in some, but not all, past productivity booms. The 1973 oil shock is perhaps the most convincing example of an adverse shock that came at the end of a productivity boom, although the question of whether the "golden era" of productivity growth had actually ended a few years earlier is still the subject of much discussion. In addition, the severe bank panic of 1893 is viewed by some as an important contributor to the depression of the 1890s; however, whether this event was an exogenous shock or an indication of earlier economic excess (as in 1929) is debatable. Of course, the U.S. economy has also experienced significant exogenous shocks in recent years: for example, the terrorist attacks of September 11, 2001, the Iraq conflict and a variety of corporate scandals. It is encouraging that the economy seems to have successfully weathered these shocks with no significant harm to productivity growth.

With so few episodes to examine, we cannot definitively identify the reasons that productivity booms come to an end, as no clear pattern emerges among the four productivity booms discussed in this paper. Of course, we have no reason to expect that all productivity booms should end because of the same circumstances. Thus, our sense is that focusing on the conditions that are most conducive to fostering extended periods of strong productivity growth will be a more fruitful line of research.

Lessons from Past Productivity Booms

Productivity booms seem to involve four key ingredients: technological innovation; the willingness and ability of owners and corporate managers to reengineer the internal organization of their firms to take maximum advantage of those innovations; financial sector innovations tailored to the forms of business organization predominating at the time; and a skilled and flexible workforce. We undoubtedly can learn many valuable lessons from these similarities, but we will touch on a few that seem particularly important.

First, many of the technological innovations associated with past productivity booms were "general purpose technologies" with widespread applicability. Such technologies often operate through various channels—through improvements in energy, transportation or communications, for example—raising productivity not only in production but also in distribution and business practices. In many cases—railroads and computers being notable examples—the productivity improvements were initially most pronounced in the production of the capital equipment embodying the new technologies. Fishlow (1966) estimates that multifactor productivity in the railroad industry rose nearly 4 percent per year, on average, between 1840 and 1900, compared with increases of around 1 percent per year for the economy as a whole. Similarly, Oliner and Sichel (2002) estimate that, since 1990, efficiency gains in the production of high-tech equipment have accounted for about half of overall multifactor productivity growth in the nonfarm business sector.

In addition, general purpose technologies tend to attract substantial new investment capital. Fishlow (2000) points out that in the 1870s, investment in transportation facilities (mainly railroads) amounted to more than 15 percent of capital formation. Similarly, in 2003, investment in high-tech equipment as a share of overall business fixed investment stood at 34 percent, up from 13 percent in 1980. Moreover, the development of these new technologies often had important intersectoral linkages to other industries (Fishlow, 2000; Mowery and Rosenberg, 2000). In the nineteenth century, for example, the construction of railroads had backward linkages to the coal, iron and steel, and machinery industries and forward linkages to the distribution sector. Likewise, in the twentieth century, the innovations in electricity, chemistry and the development of the internal combustion engine led both to widespread productivity improvements in mature industries (like steel and railroads) and the creation of new industries (like plastics and commercial air transportation).

The importance of general purpose technologies raises the question of whether governments should attempt to stimulate the development of these technologies. To be sure, government intervention has, at times, made valuable contributions to technological progress. At a general level, state and federal governments have been an important source of funding for basic research, often in research universities or federal laboratories. In addition, the legal system provides incentives for innovation through the protection of intellectual property rights; in this regard, patent laws in the United States have attempted to strike a balance—allowing the inventors of new technologies to reap the benefits of their innovations, while encouraging the timely diffusion of new technologies and limiting the damage from monopoly power (Engerman and Sokoloff, 2000).[13] In some cases, government has supported certain new technologies more directly. In the 1850s

[13] For a discussion of patent policy tradeoffs in this journal, see Gallini (2002). For a discussion of patent policy in the context of financial market innovations, see Ferguson (2003). Some observers have also emphasized that technological diffusion can be effectively achieved through the sharing of information or collective invention. See Meyer (2003), who points to the technological improvements in steel production in the 1800s and in personal computers in the 1970s as examples of such networking gains.

and after the Civil War, for example, federal land grants and state and local aid were a source of financing for railway construction. Military support for chemical research that focused on developing new materials during World War II contributed to subsequent productivity gains in the private sector. The federal government funded the building of the interstate highway system during the 1950s and 1960s, while the Department of Defense supported the development in the 1960s of the ARPANET, the precursor of the Internet.[14]

Without downplaying the role of government in encouraging invention, however, the private sector seems better equipped to identify the most promising technologies and to work out the most effective way to use these new technologies. Indeed, general purpose technologies such as the steam engine, the electric motor and the computer were developed and diffused through the economy primarily because of the profit opportunities they afforded the private sector. And even for the nineteenth-century railroads, external financing came mainly from private domestic or foreign sources; the proportion of government-funded investment by railroad companies was less than 10 percent after the Civil War (Fishlow, 2000).

In this regard, the government can arguably contribute most effectively to technological change by promoting an economic, financial and legal environment that is conducive to innovation and to the diffusion of new technologies—and then allowing businesses the flexibility to reorganize their operations in ways that permit them to take maximum advantage of new technologies. Of course, some government regulation of business and labor markets is essential for consumer and worker protection. But in retrospect, the deregulation in the 1970s and 1980s of pricing in a number of industries, such as airlines, trucking, financial services and natural gas, seems to have boosted productivity growth by allowing businesses in those industries to operate with fewer constraints and more flexibility.[15] For example, Winston (1998) cites evidence that unit operating costs have fallen 25 percent in the airline

[14] Also, each of the historical productivity booms followed the end of a major war. This sequence raises the question of whether these postwar booms reflected either a combination of new technologies and pent-up demand developed during the war or a war-related breakdown of factors previously restraining long-run growth (for example, the special interest groups emphasized by Olson, 1982). We have already noted the importance of war-related technological advances in the post–World War II productivity boom. However, it is more difficult to see such factors playing an important role in the booms that followed the Civil War and World War I. Moreover, other major wars were not followed by productivity booms, nor did the post-1995 productivity boom follow the end of a war.

[15] There has been an ongoing debate about whether protectionist measures—such as tariffs and quotas—might also be helpful in raising long-run productivity growth by encouraging the diffusion of new technologies into the domestic capital stock. Lipsey (2000) summarizes the debate for the nineteenth century, reviewing the argument that tariffs, which protected domestic markets from foreign competition, provided U.S. manufacturers the opportunity to expand more rapidly. However, even if one can build a case for targeted protectionism of "infant industries" in low-income countries, the experience of the United States in the twentieth century suggests that protectionist measures are not an effective means of promoting the diffusion of technology in an industrialized economy. Indeed, the United States has, over time, consistently and successfully responded to competitive pressures from abroad, often through technological innovations that create new markets and opportunities.

industry since deregulation, between 35 percent and 75 percent in trucking and roughly 35 percent in the natural gas industry.

Another lesson from past productivity booms is that investors must be willing to hold securities if firms are to raise the working capital they need to take advantage of the productivity potential of new technologies. As noted above, the information problems of the late 1800s and early 1900s constrained interest in common stock, and this reluctance by investors to hold equity presumably raised the overall cost of capital until methods of reducing these information problems were in place. Similarly, unless the corporate governance issues of the past few years are aggressively addressed, the damage to the financial intermediation process will undoubtedly result in a higher cost of capital. In this regard, prudent regulation of financial markets is particularly important, starting with the requirement that firms provide financial information that is extensive, accurate and interpretable in a straightforward manner.

Efforts by policymakers to provide broad access to education has also helped to stimulate economic growth by improving the ability of the workforce to adapt to technological change. In the past, a basic facility in reading, mathematics and science has been essential to workers in a wide range of occupational settings; in the future, the educational requirements of the population will likely be even greater. As a result, continued public recognition of the value of education as well as ongoing efforts to ensure widespread access to effective schooling at all levels will be indispensable.

Finally, sound macroeconomic policies have also been essential in promoting long-run economic growth. Although identifying a strong causal relationship between a healthy economy and productivity growth is difficult, several empirical observations suggest such a link. First, some evidence points to a correlation between low inflation and strong productivity growth (Fischer, 1993; Rudebusch and Wilcox, 1994).[16] Second, the number of patent applications tends to be higher in good economic times than during recessions.[17] If patenting is a valid measure of technological change, such a correlation suggests that innovation is stimulated by healthy economic conditions. Third, business fixed investment—and thus the diffusion of new technologies through renewal of the capital stock—is likely to be better maintained in an economic environment characterized by sustainable economic growth and low inflation.

[16] However, the direction of causation associated with this correlation is difficult to assess. For example, in the United States, it is sometimes argued that strong productivity growth reduced inflation in the late 1990s (Ball and Mankiw, 2002). In addition, Bruno and Easterly (1998), in a cross-country study, find evidence only of a correlation between inflation and productivity growth at high rates of inflation.

[17] Engerman and Sokoloff (2000) point out that the growth in patenting was especially high in the 1850s and 1880s, both periods of rapid economic growth. Similarly, Griliches (1990) finds a positive coefficient on real GDP growth in a regression relating the growth in patent applications to changes in real GDP and gross private domestic investment for the period 1880 to 1987. Geroski and Walters (1995) find a similar result for the United Kingdom.

Conclusion

Productivity improvements are the building blocks for increases in the standard of living. The experience in the United States suggests that extended periods of strong productivity growth are characterized by innovations in technology that are accompanied by changes in organizational structure and in business financing arrangements and by investments in human capital. Underlying these determinants of productivity growth, however, is a more fundamental factor: the willingness of society to transform itself dramatically, with the confidence that technological progress and the economic opportunities attending that progress will enable people to improve their lives. In such a society, economic growth is best fostered in an environment of economic and personal freedom and government policies that are focused on erecting sound and stable macroeconomic conditions most conducive to private-sector initiative.

■ *This paper is an edited version of a lecture delivered by Roger W. Ferguson Jr. to a joint session of the Society of Government Economists and the American Economic Association at the meetings of the Allied Social Science Associations in San Diego, California, on January 4, 2004. We are grateful to William English, Paul Harrison, Daniel Sichel and David Wilcox for their valuable insights on many of the historical examples discussed in the paper; to James Hines, Michael Palumbo, Lawrence Slifman, Charles Struckmeyer, Timothy Taylor, Mike Waldman and Joyce Zickler for helpful comments on earlier drafts; and to Jennifer Gregory for excellent research assistance. The views expressed are those of the authors and do not necessarily represent the views of other members of the Board of Governors or staff of the Federal Reserve System.*

References

Atack, Jeremy. 1986. "Firm Size and Industrial Structure in the United States during the Nineteenth Century." *Journal of Economic History.* June, 46:2, pp. 463–75.

Atack, Jeremy, Fred Bateman and William N. Parker. 2000. "The Farm, the Farmer, and the Market," in *The Cambridge Economic History of the United States, Volume 2.* Stanley Engerman and Robert Gallman, eds. New York: Cambridge University Press, pp. 245–84.

Baily, Martin Neil. 2002. "The New Economy: Post Mortem or Second Wind?" *Journal of Economic Perspectives.* Spring, 16:2, pp. 3–22.

Baker, Dean. 2002. "Is the New Economy Wearing Out?" *Challenge.* January/February, 45:1, pp. 117–21.

Balke, Nathan S. and Robert J. Gordon. 1989. "The Estimation of Prewar Gross National Product: Methodology and New Evidence." *Journal of Political Economy.* February, 97:1, pp. 38–92.

Ball, Lawrence and N. Gregory Mankiw. 2002. "The NAIRU in Theory and Practice." *Journal of Economic Perspectives.* Fall, 16:4, pp. 115–36.

Baskin, Jonathan Barron and Paul J. Miranti Jr. 1997. *A History of Corporate Finance.* New York: Cambridge University Press.

Beniger, James R. 1986. *The Control Revolution: Technological and Economic Origins of the Information Society.* Cambridge, Mass.: Harvard University Press.

Bernanke, Ben S. 1995. "The Macroeconomics of the Great Depression: A Comparative Approach." *Journal of Money, Credit, and Banking.* February, 27:1, pp. 1–28.

Bernanke, Ben S. and Martin L. Parkinson. 1991. "Procyclical Labor Productivity and Competing Theories of the Business Cycle: Some Evidence from Interwar U.S. Manufacturing Industries." *Journal of Political Economy.* June, 99:3, pp. 439–59.

Board of Governors of the Federal Reserve System. Various years. *Flow of Funds Accounts.* Washington, D.C.: Federal Reserve Board.

Board of Governors of the Federal Reserve System. Various years. *Indexes of Industrial Production.* Washington, D.C.: Federal Reserve Board.

Bruno, Michael and Michael Easterly. 1998. "Inflation Crises and Long-Run Growth." *Journal of Monetary Economics.* February, 41:1, pp. 3–26.

Brynjolfsson, Erik and Lorin M. Hitt. 2000. "Beyond Computation: Information Technology, Organizational Transformation and Business Performance." *Journal of Economic Perspectives.* Fall, 14:4, pp. 23–48.

Chandler, Alfred D. 1977. *The Visible Hand: The Managerial Revolution in American Business.* Cambridge, Mass.: Belknap Press of Harvard University Press.

Cortada, James W. 1993. *Before the Computer: IBM, NCR, Burroughs, & Remington Rand & the Industry They Created, 1865–1956.* Princeton, N.J.: Princeton University Press.

David, Paul A. 1969. "Transportation Economics and Economic Growth: Professor Fogel On and Off the Rails." *Economic History Review.* December, 22:3, pp. 506–25.

David, Paul A. 1990. "The Dynamo and the Computer: An Historical Perspective on the Modern Productivity Paradox." *American Economic Review.* May, 80:2, pp. 355–61.

Easterlin, Richard A. 1961. "Regional Income Trends, 1840–1950," in *American Economic History.* Seymour E. Harris, ed. New York: McGraw-Hill Press, pp. 525–47.

Engerman, Stanley and Kenneth L. Sokoloff. 2000. "Technology and Industrialization 1790–1914," in *Cambridge Economic History of the United States, Volume 2.* Stanley Engerman and Robert Gallman, eds. Cambridge: Cambridge University Press, pp. 367–401.

Ferguson, Roger W. Jr. 2003. "Patent Policy in a Broader Context." Remarks at the 2003 Financial Markets Conference of the Federal Reserve Bank of Atlanta, April.

Field, Alexander J. 2003. "The Most Technologically Progressive Decade of the Century." *American Economic Review.* September, 93:4, pp. 1399–413.

Fischer, Stanley. 1993. "The Role of Macroeconomic Factors in Growth." *Journal of Monetary Economics.* December, 32:3, pp. 485–512.

Fishlow, Albert. 1966. "Productivity and Technological Change in the Railroad Sector, 1840–1910," in *Output, Employment, and Productivity in the United States after 1800.* Dorothy S. Brady, ed. New York: National Bureau of Economic Research, pp. 583–646.

Fishlow, Albert. 2000. "Internal Transportation in the Nineteenth and Early Twentieth Centuries," in *Cambridge Economic History of the United States, Volume 2.* Stanley Engerman and Robert Gallman, eds. Cambridge: Cambridge University Press, pp. 543–642.

Fogel, Robert W. 1979. "Notes on the Social Saving Controversy." *Journal of Economic History.* March, 39:1, pp. 1–50.

Freeman, Richard B. 2002. "The Labour Market in the New Information Economy." *Oxford Review of Economic Policy.* Autumn, 18:3, pp. 288–305.

Galambos, Louis. 2000. "The U.S. Corporate Economy in the Twentieth Century," in *Cambridge Economic History of the United States, Volume 3* Stanley Engerman and Robert Gallman, eds. Cambridge: Cambridge University Press, pp. 927–67.

Gallini, Nancy T. 2002. "The Economics of Patents: Lessons from Recent U.S. Patent Reforms." *Journal of Economic Perspectives.* Spring, 16:2, pp. 131–54.

Gallman, Robert E. 1966. "Gross National Product in the United States, 1834–1909," in *Output, Employment, and Productivity in the United States after 1800.* Dorothy S. Brady, ed. New York: National Bureau of Economic Research, pp. 3–76.

Geroski, P. A. and C. F. Walters. 1995. "Innovative Activity Over the Business Cycle." *Economic Journal.* July, 105:431, pp. 916–28.

Goldin, Claudia. 2000. "Labor Markets in the Twentieth Century," in *Cambridge Economic History of the United States, Volume 3.* Stanley Engerman and Robert Gallman, eds. Cambridge: Cambridge University Press, pp. 549–623.

Goldin, Claudia and Lawrence F. Katz. 1998. "The Origins of Technology-Skill Complementarity." *Quarterly Journal of Economics.* August, 113:3, pp. 693–732.

Gordon, Robert J. 1992. "Productivity in the Transportation Sector," in *Output Measurement in the Service Sectors.* National Bureau of Economic Research Studies in Income and Wealth. Zvi Griliches, ed. Chicago: University of Chicago Press, pp. 371–422.

Gordon, Robert J. 2000a. "Interpreting the 'One Big Wave' in U.S. Long-Term Productivity Growth," in *Productivity, Technology, and Economic Growth.* Bart van Ark, Simon Kuipers and Gerard Kuper, eds. New York: Kluwer Publishers, pp. 19–65.

Gordon, Robert J. 2000b. "Does the 'New Economy' Measure Up to the Great Inventions of the Past?" *Journal of Economic Perspectives.* Fall, 14:4, pp. 49–74.

Griliches, Zvi. 1988. "Productivity Puzzles and R&D: Another Nonexplanation." *Journal of Economic Perspectives.* Fall, 2:4, pp. 9–21.

Griliches, Zvi. 1990. "Patent Statistics as Economic Indicators: A Survey." *Journal of Economic Literature.* December, 28:4, pp. 1661–707.

Hawkins, David F. 1963. "The Development of Modern Financial Reporting Practices among American Manufacturing Companies." *Business History Review.* Winter, 37:1, pp. 135–68.

James, John A. and Jonathan S. Skinner. 1985. "The Resolution of the Labor-Scarcity Paradox." *Journal of Economic History.* September, 45:3, pp. 513–40.

Johnston, R. B. 1982. *The Economics of the Euro-Market.* New York: St. Martin's Press.

Jorgenson, Dale W., Mun S. Ho and Kevin Stiroh. 2002. "Projecting Productivity Growth: Lessons from the U.S. Growth Resurgence." *Federal Reserve Bank of Atlanta Economic Review.* Third Quarter, 87:3, pp. 1–13.

Kane, Thomas J. and Cecilia Elena Rouse. 1999. "The Community College: Educating Students at the Margin Between College and Work." *Journal of Economic Perspectives.* Winter, 13:1, pp. 63–84.

Keeler, Theodore E. and John S. Ying. 1988. "Measuring the Benefits of a Large Public Investment: The Case of the U.S. Federal-Aid Highway System." *Journal of Public Economics.* June, 36:1, pp. 69–85.

Kendrick, John W. 1961. *Productivity Trends in the United States.* Princeton, N.J.: Princeton University Press.

Kindleberger, Charles P. 1993. *A Financial History of Western Europe.* New York: Oxford University Press.

Kleinknecht, Alfred. 1987. *Innovation Patterns in Crisis and Prosperity: Schumpeter's Long Cycle Reconsidered.* New York: St. Martin's Press.

Kuznets, Simon S. 1946. *National Product Since 1869.* New York: National Bureau of Economic Research.

Lipsey, Robert E. 2000. "U.S. Foreign Trade and the Balance of Payments 1800–1913," in *Cambridge Economic History of the United States, Volume 2.* Stanley Engerman and Robert Gallman, eds. Cambridge: Cambridge University Press, pp. 685–732.

Madrick, Jeffrey. 2002. "Optimism Needs a Warning Label When It Comes to Forecasting Productivity." *New York Times.* January 24, p. C2.

Mansfield, Edwin. 1965. "Innovation and Technical Change in the Railroad Industry," in *Transportation Economics.* New York: National Bureau of Economic Research, pp. 169–97.

Margo, Robert A. 2000. "The Labor Force in the Nineteenth Century," in *Cambridge Economic History of the United States, Volume 2.* Stanley Engerman and Robert Gallman, eds. Cambridge: Cambridge University Press, pp. 207–43.

Mensch, Gerhard. 1979. *Stalemate in Technology: Innovations Overcome the Depression.* Cambridge, Mass.: Ballinger.

Meyer, Peter B. 2003. "Episodes of Collective Invention." Bureau of Labor Statistics Working paper, Washington, D.C., August.

Miranti, Paul J. Jr. 2001. "U.S. Financial Reporting Standardization: 1840–2000." *World Development Report 2002: Institutions for Markets.* Washington, D.C.: World Bank.

Mowery, David and Nathan Rosenberg. 2000. "Twentieth-Century Technological Change," in *Cambridge Economic History of the United States, Volume 3.* Stanley Engerman and Robert Gallman eds. Cambridge: Cambridge University Press, pp. 803–925.

Nelson, Richard R., Merton J. Peck and Edward D. Kalachek. 1967. *Technology, Economic Growth, and Public Policy.* Washington, D.C.: The Brookings Institution.

Oliner, Stephen D. and Daniel E. Sichel. 1994. "Computers and Output Growth Revisited: How Big is the Puzzle?" *Brookings Papers on Economic Activity.* 2, pp. 273–317.

Oliner, Stephen D. and Daniel E. Sichel. 2002. "Information Technology and Productivity: Where are We Now and Where are We Going?" *Federal Reserve Bank of Atlanta Economic Review.* Third Quarter, 87:3, pp. 15–44.

Olson, Mancur. 1982. *The Rise and Decline of Nations.* New Haven: Yale University Press.

Paul, Catherine J. Morrison and Donald S. Siegel. 2001. "The Impacts of Technology, Trade and Outsourcing on Employment and Labor Composition." *Scandinavian Journal of Economics*. 103:2, pp. 241–64.

Paullin, Charles O. 1932. *Atlas of the Historical Geography of the United States*. Washington, D.C.: Carnegie Institute and American Geographical Society.

PricewaterhouseCoopers/Thompson Venture Economics/National Venture Capital Association. Various years. *MoneyTree Survey*.

Rhode, Paul W. 2002. "Gallman's Annual Output Series for the United States, 1834–1909." National Bureau of Economic Research Working Paper No. 8860, Cambridge, Mass., April.

Roach, Stephen. 2003. "Clueless on Productivity." *Global Economic Forum*. Morgan Stanley; Available at ⟨http://www.morganstanley.com/GEFdata/digests/20030905-fri.html⟩.

Rockoff, Hugh. 2000. "Banking and Finance, 1789–1914," in *Cambridge Economic History of the United States, Volume 2*. Stanley Engerman and Robert Gallman, eds. Cambridge: Cambridge University Press, pp. 643–84.

Romer, Christina D. 1989. "The Prewar Business Cycle Reconsidered: New Estimates of Gross National Product, 1869–1908." *Journal of Political Economy*. February, 97:1, pp. 1–37.

Rudebusch, Glenn D. and David W. Wilcox. 1994. "Productivity and Inflation: Evidence and Interpretations." Unpublished manuscript, Board of Governors of the Federal Reserve System.

Schmookler, Jacob. 1966. *Invention and Economic Growth*. Cambridge, Mass.: Harvard University Press.

Sichel, Daniel E. 1997. *The Computer Revolution: An Economic Perspective*. Washington, D.C.: The Brookings Institution.

Spitz, P. H. 1988. *Petrochemicals: The Rise of an Industry*. New York: John Wiley.

U.S. Bureau of Economic Analysis. 1966. *U.S. Direct Investment Abroad, 1966*. Washington, D.C.: BEA.

U.S. Census Bureau. 1997. *Historical Statistics of the United States on CD-ROM: Colonial Times to the Present*. Susan Carter, Scott Gartner, Michael Haines, Alan Olmstead, Richard Sutch and Gavin Wright, eds. New York, N.Y: Cambridge University Press.

U.S. Census Bureau. 2001. *Statistical Abstract of the United States*. Austin, Tex.: Reference Press.

U.S. Department of Education, National Center for Education Statistics. Various years. *Digest of Education Statistics*. Washington, D.C.: Government Printing Office.

U.S. Patent and Trademark Office. 2002. *U.S. Patent Activity, 1790–Present*. Washington, D.C.: USPTO.

Vernon, Raymond. 1971. *Sovereignty at Bay: The Multinational Spread of U.S. Enterprises*. New York: Basic Books.

White, Eugene N. 2000. "Banking and Finance in the Twentieth Century," in *Cambridge Economic History of the United States, Volume 3*. Stanley Engerman and Robert Gallman, eds. Cambridge: Cambridge University Press, pp. 743–802.

Winston, Clifford. 1998. "U.S. Industry Adjustment to Economic Deregulation." *Journal of Economic Perspectives*. Summer, 12:3, pp. 89–110.