Roger W Ferguson, Jr: Lessons from past productivity booms

Speech by Mr Roger W Ferguson, Jr, Vice-Chairman of the Board of Governors of the US Federal Reserve System, at the meetings of the American Economic Association, San Diego, 4 January 2004.

The references for the speech can be found on the Board of Governors of the Federal Reserve System's website.

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As we are all well aware, the United States has been enjoying significantly faster productivity growth for the past eight years or so than it did over the preceding two decades. Since 1995, labor productivity has risen at an average annual rate of about 3 percent, up from an average annual rate of around 1-1/2 percent between 1973 and 1995. And in the past two years alone, output per hour has increased more than 5 percent per year.

The significance of the improvement since 1995 can hardly be overstated, even after taking into account the cyclical component of the most recent quarters. If productivity were to continue to improve at an average annual rate of 3 percent, the standard of living in the United States would double roughly every twenty-four years. If, on the other hand, productivity growth were to revert to an average annual pace of 1-1/2 percent, a doubling in the standard of living would occur only every forty-seven years. Many observers-including some economists-argue that the present era of robust trend productivity growth will soon come to an end. Others are more optimistic and argue that the potential gains to productivity from the technological advances associated with the computer revolution are far from complete.[1] Because productivity growth is critical to economic welfare, assessing the likelihood of these alternative outcomes is of considerable interest.

In thinking about this issue, it is worth recognizing that periods of strong trend productivity growth, although perhaps novel to many of us, are not new to the U.S. economy. In fact, three earlier periods seem to stand out from the historical record as especially worthy of further scrutiny for the lessons they may offer regarding the current episode: a period in 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]

Of particular note is that in at least two of the earlier episodes, heightened productivity growth lasted for an extended period - roughly twenty years or so. Thus, one objective in examining these previous productivity booms is to see whether we can glean any insights into the best ways to sustain the current episode of strong productivity growth. To be sure, each period mentioned can be associated with particular advances in technology, 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 other complementary factors - including aspects of the labor market, of the business environment, or of government policies - 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.

Similarly, examining the historical record may shed light on the sustainability of the current boom. Do productivity booms simply run out of steam and die natural deaths? Or are they cut short by economic imbalances, exogenous shocks, or detrimental government policies? And, if the latter, are these cessations inevitable?

At the outset, I should note that this lecture is co-authored with William Wascher, who is a member of the staff at the Board of Governors. To provide a roadmap of where we intend to go, I want to start by setting out some basic facts about previous periods of strong productivity growth in the United States. I will, of course, begin with some numbers. But I also want to discuss some of the technological

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1 For a recent assessment of the new economy, see Martin Baily's Distinguished Lecture on Economics in Government (Baily 2002).

2 Others will undoubtedly disagree with this taxonomy. Robert Gordon (2000), 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. And from a standpoint of technological advance, that characterization may well 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 appropriate.

innovations that contributed to these productivity booms and about the supportive roles played by changes in the organization of American businesses and the structure of financial markets, and by the U.S. education system. Finally, I will spend some time on the lessons that we think can be learned from what, in many ways, are striking similarities across the three previous episodes and the current one.

Identifying previous productivity booms

I should also note at this point that even the basic facts about economic growth, not to mention the interpretation of those facts, are sometimes subject to considerable debate. Some of these disagreements undoubtedly result from the lack of consistent information on U.S. productivity before data from the Bureau of Labor Statistics (BLS) became available in 1948. For this earlier period, we use data developed in the early 1960s by John Kendrick, who constructed estimates of GDP consistent with the prevailing definitions in the National Income and Product Accounts going back to the 1870s (which had as their basis estimates made by Simon Kuznets in the 1940s).[3] 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 in different ways, the additional refinements focus primarily on the cyclical properties of output and do not significantly alter the qualitative statements about long-run growth made here. A number of economic historians - most notably Robert Gallman - have estimated U.S. GDP for the period before the Civil War.[4] However, given that their estimates are surely less reliable than those for the later, more industrialized period, we have elected to limit the focus of this lecture to the post-Civil War period.

These caveats aside, average growth rates of productivity over various periods are presented in the table. We will focus on labor productivity (the first column) because that measure is the best indicator of improvement in the nation's standard of living. For the entire period from 1870 to 2003, labor productivity has risen at an average rate of around 2 percent per year. However, productivity growth has not proceeded in a steady fashion. We have chosen time periods for our analysis that smooth through the business cycle, which is a significant source of shorter-term changes in rates of productivity growth. More important for this discussion is the variation in labor productivity growth that has occurred over longer stretches of time, with periods of robust growth interspersed with periods of more modest productivity gains.

Using the Kendrick data as a guide and recognizing that the choice of any particular period is somewhat subjective, we take as the first episode of strong productivity growth - or productivity boom, if you will - roughly the period from 1873 to 1890. During this period, labor productivity rose more than 2-1/2 percent per year, a rate thought to be considerably higher than the average growth experienced over the first 100 years of the United States.[5] An important element of the analysis of this and other periods is the decomposition of output per hour into its underlying sources, including the contributions of multifactor productivity, capital deepening, and labor quality. In this regard, Kendrick's decomposition suggests that labor productivity growth in the late 1800s was fueled importantly by capital investment.[6]

During the next three decades, from 1890 to 1917, the growth rate of labor productivity slowed to an average pace of only 1-1/2 percent per year, with modest rates of growth both in the capital stock and in multifactor productivity. The United States then enjoyed a relatively brief spurt in productivity until about 1927, with labor productivity rising about 3-3/4 percent per year and multifactor productivity up around 2 3/4 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 through the Great Depression and World War II, largely reflecting a lack of capital

[3] See Kendrick (1961) and Kuznets (1946).

[4] See, for example, Gallman (1966) and Rhode (2002).

[5] 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.

[6] 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.

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.

Productivity growth since World War II is more familiar to us and is based on more reliable data - those constructed as part of the multifactor productivity program at the BLS. According to these data, labor productivity rose at an annual rate of close to 3 percent from 1948 to 1973 - a period sometimes referred to as the golden age of productivity growth. 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. The productivity slowdown of the 1970s and 1980s is also well known to us, and its possible causes have been the subject of much research. Labor productivity growth slowed to an average pace of 1.4 percent per year over this period, while multifactor productivity growth fell to a pace of 0.4 percent, the slowest pace of any of the periods shown on the table. Finally, labor productivity growth has averaged about 3 percent at an annual rate since 1995, 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 new technologies. The boom after the Civil War, for instance, appears to have had its genesis in 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.

In particular, the widespread introduction of steam engines and machinery driven by new sources of energy enabled firms to move away from sources of waterpower and closer to areas where inputs - including labor and raw materials - were more readily available. The Midwest - where sources of waterpower were 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. This regional shift in economic activity is illustrated by a sharp rise in the share of personal income generated in the Midwest between 1840 and 1880 (from 20 percent to 35 percent), and the commensurate decline in the share of income generated in the Northeast (from 43 percent to 31 percent).[7]

The increase in the importance of railroad transportation also helped raise productivity growth in the second half of the nineteenth century.[8] 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. And the growth of telegraphy enabled railroads to better 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.[9]

The expansion of the railroads drove transportation costs sharply lower and allowed a significant increase in market size. Whereas, in 1830, the transportation of goods from New York to Chicago had required three weeks even during the warmer months of the year, by 1870, it could be accomplished in three days any time of the year.[10] In addition, the construction of new rail lines in western states opened those markets to a wide range of East Coast and Midwest manufacturers. Moreover, some of the benefits of the productivity improvements in the railroad industry were passed on to producers in the form of lower costs of transporting goods. Freight rates fell from 2-1/4 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.[11]

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[7] Easterlin (1961).

[8] How much the railroad contributed to economic growth in the late nineteenth century is the subject of some disagreement. See, for example, David (1969), Fishlow (2000), and Fogel (1979).

[9] U.S. Census Bureau (1997), Series Q321, and Fishlow (1966).

[10] See Paullin (1932). Before the railroads, goods were transported by canals, which often did not operate during the winter.

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

Another major technological advance in the mid-1800s was the telegraph. Besides aiding the expansion of railroads by improving the coordination of rail traffic, the telegraph sharply reduced the costs of communicating in many other industries. And judging from the rapid growth in its use - the number of messages handled rose from about 9 million in 1870 to nearly 56 million in 1890 - the telegraph undoubtedly contributed to better decisionmaking and higher productivity throughout the economy.[12]

Agriculture also was increasingly mechanized in the decades immediately after the Civil War, though the change 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 more 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.[13]

In the productivity boom of the early twentieth century, the chief technological innovation was most likely the spread of electrification to the factory floor. As Paul David and others have extensively documented, the use of electric motors in the production process increased substantially in the first quarter of the century.[14] In particular, 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.[15]

A major benefit of electric motors was that they enabled each machine in a factory to be powered by its own motor. This allowed manufacturing plants to be organized in a way that maximized the efficient movement of materials rather than the efficient transmission of power, and it facilitated the spread of continuous processing techniques and the assembly lines made popular by Henry Ford. Indeed, as electric power became less costly - aided by a steep reduction in regulated electricity rates after World War I - its use increased sharply, and factory productivity rose significantly. By one estimate, productivity growth in the manufacturing sector as a whole rose about 5-1/2 percent per year between 1919 and 1929.[16]

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, the use of which in motorized vehicles led to 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, and the demand for such equipment rose quite sharply between 1900 and the late 1920s. Indeed, 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.[17]

The productivity gains of the 1950s and 1960s, in part, had their roots in the technological innovations arising out of research sponsored by the military during World War II.[18] For example, although 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 led to mass production of the first synthetic polymer from petroleum-based feedstocks. Similarly, production of polyethylene, a petrochemical-based plastic discovered in the 1930s, jumped sharply in the 1940s because of its widespread use in military equipment. And, 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 range of pharmaceuticals.

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[12] U.S. Census Bureau (1997), Series R48.

[13] See Atack, Bateman, and Parker (2000).

[14] See, for example, David (1990) and Mowery and Rosenberg (2000)

[15] U.S. Census Bureau (1997), Series P70.

[16] Kendrick (1961), p. 152.

[17] See Cortada (1993), figure 3.1.

[18] This section draws from Mowery and Rosenberg (2000).

The commercialization of these wartime 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, grew sharply after the war, while additional technological advances isolated new forms of synthetics and further reduced production costs for chemicals and pharmaceuticals. Overall, production in the rubber and plastic products industry rose nearly 7 percent per year between 1947 and 1970, while the output of the chemical products industry rose more than 8 percent annually over the same period.[19]

Two other notable technological advances during this period were the invention of the transistor in 1947 and the use of the jet engine in commercial aircraft. 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.[20] Similarly, the introduction of the Boeing 707 in 1958 sharply reduced the time and cost of transporting passengers and freight. In particular, according to estimates by Gordon (1992), productivity in the commercial airline industry rose 7 percent per year during the 1960s, well above the rate of labor productivity growth for the economy as a whole.[21]

For purposes of comparison, the technological origins of the more recent computer revolution 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 how firms interact with their customers, in ways that have raised the productivity of the economy. In the retail sector, the Internet stores made popular by Amazon.com have been adopted by nearly all large retail chains; in banking, it is now routine for customers to pay bills online; and for airlines, Internet reservations and e-tickets are the norm. Moreover, throughout the goods economy, from manufacturing to retailing, innovations in inventory management practices made possible by new technologies have substantially reduced costs.

An important point about technological change is that, in most cases, the invention of the technologies that stimulated the productivity growth in these boom periods took place 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. And as we all know, the absence of a significant contribution to productivity growth from computers, which were first introduced in 1945, was a puzzle to many economists as late as the mid-1990s.

What then facilitated the translation of these innovations into gains in productivity? At one level, the delay reflected the challenges of developing commercial applications for the new technologies. The lag from a new invention to a new product or process was sometimes quite long because of the additional scientific research required to demonstrate its practicality. In addition, in many cases, new technologies diffused into the capital stock relatively slowly. 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.

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[19] Board of Governors of the Federal Reserve System, Indexes of Industrial Production. By comparison, overall manufacturing IP rose about 4-1/2 percent per year from 1947 to 1970.

[20] Board of Governors of the Federal Reserve System, Indexes of Industrial Production.

[21] Of course, the invention and commercial use of the airplane itself was a technological innovation that predated the jet engine. In particular, the introduction of commercial air travel in the late 1920s represented a substantial improvement over existing 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.

Sources of past productivity booms: organizational change

A careful examination of past productivity booms also points to substantial changes in business practices and in the organization of firms as a key factor enabling businesses to achieve the potential productivity gains associated with new technologies.[22] 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.

For example, before the Civil War, most businesses were either sole proprietorships or partnerships serving local markets and consisted of small shops employing skilled workers involved in each aspect of the production process. At the same time that 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 optimal firm size 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, median firm size rose from $24,000 in 1850 to more than $200,000 in 1870.[23] In addition, large wholesalers (and later, retailers) emerged to take advantage of increased distributional efficiencies to sharply reduce the costs of moving commodities and manufactured goods from the farm or factory to retailers' shelves.

These larger enterprises typically had to confront communications challenges not faced by smaller businesses. In particular, effective internal information flows were often crucial to the success of firms producing or distributing large volumes of inputs and outputs. The telegraph and the railroad-based postal service made prompt communication over great distances possible. But firms also had to set up hierarchical management systems to control the production process and to coordinate the flow of goods across the distribution system in order to take advantage of the economies of scale presented by technological change.

Advances in production processes in the early 1900s led to new challenges and opportunities for business organization. As noted above, the diffusion of the electric motor throughout the factory 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 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. Indeed, 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 nonproduction activities.[24] To compete in retail markets, firms needed to understand what products consumers wanted and to enable 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 and advertising departments arose within large corporations, as did accounting departments. Also, with large corporations now more sensitive to their market share and their cost advantage over their competitors, they began to develop applied research departments to foster innovations in their industries.

After World War II, changes in the organization of the firm took two forms. The first was an increasing tendency by corporate managers to split the firms' operations into separate divisions, each with its own manufacturing and marketing departments. This multidivisional approach was well suited to the technological changes of the 1940s and 1950s, as many innovations during that period led to the

[22] Chandler (1977) provides a detailed discussion of such changes.

[23] Atack (1986).

[24] This section draws from Galambos (2000).

manufacturing of diverse product lines by a single company, DuPont and Monsanto being key examples.[25]

This multidivisional structure also turned out to be an effective method of handling corporate operations in different geographic areas; and indeed, the second major organizational innovation during this period was the rise of the multinational corporation. 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. By one estimate, such multinational corporations accounted for nearly 35 percent of total U.S. corporate assets by 1966.[26]

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 dominated by large, well-established firms. And 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.

At the same time, much of the rapid technological innovation in this period 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.[27] Of course, as we know from the dot-com experience, 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 predominate form of business organization in each period.[28]

For example, 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 actively issuing stocks and bonds in the 1850s.[29] With the need for greater capital investments and the sharp increases in the scale of operations of many firms after the Civil War, however, businesses in other industries also 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.[30] 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 often 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 equity of the owners of the firm, was often used when assets were insufficient to secure the loan. Thus, despite the prevalence of information problems, financial intermediaries were able to provide firms with external sources of funds, making possible the rapid buildup in the capital stock that took place in the late 1800s. For example, the total

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25 Baskin and Miranti (1997).

26 U.S. Bureau of Economic Analysis (1966).

27 U.S. Census Bureau (2001).

28 This section draws from Baskin and Miranti (1997) and White (2000).

29 Chandler (1977).

30 As Fishlow (2000) notes, an exception to this were railroad companies, which sold sizable amounts of common stock to investors seeking large capital gains following the completion of new construction projects.

value of bank loans rose from less than $1 billion in 1870 to more than $6 billion in the early 1890s, a notable increase in nominal value during a time when, if anything, the aggregate price level was falling.[31]

In contrast, the years after World War I were 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.[32] And, by one estimate, the number of individuals holding stock increased from 500,000 in 1900 to 10 million by 1930.[33]

The rise in the public's interest in common stock occurred for several reasons. First, and probably most importantly, the profitability of large corporations during the early 1900s was accompanied by an expanding middle and upper class 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. As the main way to share in these capital gains was to purchase some ownership in those corporations, these individuals increasingly looked to invest their savings in the stock market.

At about the same time, the informational problems that had constrained interest in common stock through the early 1900s were being reduced. Rising demand from investors in the late 1800s for information about railroad companies had led to the proliferation of newsletters watching developments in that industry, and similar publications soon sprang up to provide information on other traded securities. These newsletters eventually 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. In addition, with a greater recognition of the need to address investors' concerns about risk, more public companies regularly issued audited financial statements.[34]

Interest in common stock was also boosted 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 encourage holdings of their securities. 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.

Given the relative prosperity of the post-World War II period, nonfinancial corporations were able to generate significant increases in internal funds. Even so, the growth of investment spending over this period noticeably outpaced the rise in retained earnings, and thus these corporations turned to the capital markets to fill the widening gap. In response, both bond and equity issuance rose rapidly in absolute terms, and the ratio of external financing to overall capital spending increased from an average of around 30 percent in the late 1940s to more than 40 percent in the early 1970s.[35]

There were two specific developments in financial markets during this period that 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.[36] 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

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31 U.S. Census Bureau (1997), Series X581.

32 U.S. Census Bureau (1997), Series X531.

33 Hawkins (1963).

34 Miranti (2001).

35 Board of Governors of the Federal Reserve System, Flow of Funds Accounts.

36 See Johnston (1982) and Kindleberger (1993). Although no direct data on the size of the Eurodollar market are available, flow of funds data indicate that foreign holdings of U.S. corporate bonds rose from about $500 million in the mid-1950s to about $2 1/2 billion in 1970.

funds and brokerage houses, enabled smaller investors (either explicitly or implicitly) to further diversify their portfolios.

More recently, financial markets have continued to evolve to meet the financing needs of the business sector and the concerns of investors. In particular, in response to the proliferation of start-up businesses and, for many firms, a riskier economic environment, financial intermediaries have expanded the range of financing alternatives available to businesses and have made marked improvements in quantifying and managing risk.

For larger lower-rated corporations that have significant default risk, the expansion of the so-called junk bond market has offered the capability to raise funds even when other sources of financing were less available. For example, junk bond issuance rose from about $11 billion in 1984 to more than $100 billion in 2001, while the par value of outstanding junk-rated debt has increased from less than $100 billion in the mid 1980s to nearly $700 billion today.[37]

For smaller and yet-riskier firms, venture capital and initial public offerings have been important sources of financing. For example, venture capital investments, which were negligible in the early 1980s, rose to more than $100 billion in 2000, although they have since dropped back.[38] 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.[39]

In terms of managing risk, many large financial institutions have, over the past decade, increasingly adopted internal credit-risk models to improve their ability to assess in real time the riskiness of their portfolios. In addition, financial-market innovations, including securitizations, credit derivatives, and an improved secondary loan market, have allowed these institutions to better manage their exposure to such risks. These improvements in risk management may help to explain why financial institutions weathered the recent economic downturn so well relative to their difficulties in previous recessions.

Sources of past productivity booms: human capital accumulation

The fourth ingredient underlying the productivity booms of the past involves labor input-specifically, the availability of a workforce capable of bringing to fruition the possibilities opened up by the technological innovations. Technological advances have not increased the demand for all skill sets equally. For example, the shift in manufacturing production from artisanal shops in the mid-1800s to factories after the Civil War led to a disproportionate increase in the demand for unskilled labor to operate the new machines. But, as I noted earlier, increases in the optimal size of firms and the growth of businesses dedicated to mass distribution and mass production also increased the demand for workers who could perform clerical and managerial tasks. Indeed, the percent of men who were employed in white-collar occupations rose from less than 5 percent in 1850 to nearly 18 percent by 1900.[40]

The demand for white-collar workers continued to increase in the early twentieth century with the further expansion in corporate size and the new focus on activities outside traditional production. In particular, these additional activities required a new set of managers to control and coordinate the diverse functions of the corporation and an increase in clerical workers to process the increased flow of information associated with vertical integration. As a result, nonproduction workers as a share of the total labor force rose from 6-1/2 percent in 1880 to nearly 25 percent by 1930.[41]

Moreover, contrary to what had been true earlier, manufacturing firms that were using more advanced technologies in the early 1900s also tended to hire more-capable and more highly educated workers. In particular, in the 1920s, the industries that were more likely to employ high-school-educated blue-collar workers tended to be the same industries that were further along in adopting the new technologies, suggesting that the basic reading and mathematics skills acquired in high schools were

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[37] Based on data from Thompson Financial Securities Data Corporation and Moody's Investors Service.

[38] PricewaterhouseCoopers/Thomson Venture Economics/National Venture Capital Association, MoneyTree Survey.

[39] Thompson Financial Securities Data Corporation.

[40] Margo (2000), pp. 215-16.

[41] Beniger (1986).

valued by firms in these industries. That wage levels in these industries tended to be higher than for the manufacturing sector as a whole is a further indication that they employed workers with more skills.[42]

Similarly, throughout the rest of the twentieth century, skilled labor and new technologies appeared to be complements in production. The 1950s and 1960s saw a significant increase in the share of the workforce in professional and technical occupations, with especially rapid growth among engineers and technicians.[43] And the 1980s and 1990s saw a rise in the wage premium for higher-skilled workers, as well as a sharp increase in the demand for workers with computer-related skills. In contrast, lower-skilled workers have suffered in recent years from competitive pressures that are related in part to the outsourcing of low-skilled jobs abroad.

The institution of universal education in the United States has allowed our workforce to adapt to the changing skill requirements of the economy. In the late 1800s, school enrollment rates among children held steady at about 50 percent and high school graduation rates remained below 5 percent, a pattern consistent with the absence of a significant wage premium for educated labor. However, as the premium for education widened in the early 1900s, enrollment rates in secondary schools increased steadily, and the high school graduation rate rose to more than 25 percent by the late 1920s. Similarly, partly reflecting rising demand for college-educated labor in the 1950s and 1960s, the percentage of 18 to 24 year olds enrolled in college rose from about 14 percent in 1950 to roughly 25 percent in 1970.[44]

After stagnating in the 1970s and 1980s, college enrollment rates among youths began to rise again in the 1990s, reflecting a further widening in the skill premium for workers with a college degree. Moreover, enrollments at community colleges increased about 30 percent between 1985 and 2000, and the percent 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.[45] These changes likely reflect, in part, efforts by lesser-skilled adults to retool their skills.

In sum, the productivity booms of the past seem to have involved 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; complementary innovations in the financial sectors specifically tailored to the forms of business organization predominating at the time; and the availability of a workforce sufficiently educated to actualize the potential implicit in the technological innovations. From the standpoint of economic policy, we undoubtedly stand to learn a number of valuable lessons from these similarities, but let me touch on a few that I think are particularly important.

Lessons from past productivity booms

First, many of the technological innovations associated with past productivity booms were general purpose technologies (GPTs) with widespread applicability. Such technologies have operated through a variety of channels, raising productivity not only in production, but also in distribution and business practices. In many cases - railroads and computers, for example - the productivity improvements were initially most pronounced in the production of the capital equipment embodying the new technologies. In particular, Fishlow (1966) estimates that multifactor productivity in the railroad industry rose nearly 4 percent per year, on average, between 1840 and 1900, as compared with increases of around 1 percent per year for the economy as a whole. And, 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, such general purpose technologies typically draw in substantial amounts of new investment capital. For example,

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42 See Goldin and Katz (1998).

43 U.S. Census Bureau (1997), Series D233-D682.

44 U.S. Census Bureau (1997), Series H433, H701. The increase in college enrollments during this period likely was also boosted by the use of college deferments during the Vietnam War.

45 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 post-secondary education or career-related courses.

Fishlow (2000) points out that in the 1870s, investment in transportation facilities 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 42 percent, up from 19 percent in 1980.[46]

The importance of general purpose technologies raises the question of whether governments should attempt to stimulate the development of particular GPTs, perhaps through some type of industrial policy. To be sure, government intervention has, at times, contributed to specific technological innovations. Government support in the 1800s - through federal land grants and state and local aid - was one source of financing for railway construction in the 1850s and after the Civil War. Military support for chemical research that focused on developing new materials during World War II obviously contributed to productivity gains in the private sector in the 1950s and 1960s. And, the Department of Defense supported the development in the 1960s of the ARPANET, the predecessor of the Internet of today.

However, many, if not most, of the general purpose technologies of the past two centuries have had their genesis in the private sector. The steam engine, the electric motor, and the computer were developed and diffused through the economy largely as a result of the profit opportunities afforded by those new technologies. And, even for railroads, external financing came primarily from private domestic or foreign sources; estimates place the proportion of government funding in nominal investment by railroad companies at less than 10 percent after the Civil War.[47]

In the United States, the government has contributed 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. Federal funding of basic research, often in research universities or federal laboratories, obviously comprises an important part of this contribution. However, another key component of this environment has been the protection of intellectual property rights. Patent laws in the United States have encouraged innovation by attempting to strike a careful balance - allowing the inventors of new technologies to reap the benefits of their innovations, while at the same time encouraging the timely diffusion of new technologies and limiting the damage from monopoly power.[48] In the past, patent laws have primarily emphasized protection of the new technologies or production processes associated with invention. Given that recent innovations have, to an increasing extent, encompassed the transformation of electronic data to create new methods of business practices, the challenge today is to ensure that such innovations are afforded the appropriate degree of protection - ensuring that innovators are rewarded for their ideas but not granting them so wide a range of territory in the property-rights battlefield that they acquire a stranglehold on the economy and, perversely, are allowed to choke off the innovation that they helped create.[49]

Similarly, allowing businesses the flexibility to reorganize their operations in ways that permitted them to take maximum advantage of new technologies has been instrumental in translating technological innovations into higher productivity in all four episodes. Likewise, U.S. labor markets have been quite effective at reallocating the workforce in response to technological changes. Of course, some government regulation of business and labor markets is absolutely essential, but such regulatory policies must be designed taking account not only of perceived advantages but also of economic costs. For example, it seems clear in retrospect that the deregulation of a number of industries in the 1970s and 1980s, such as airlines, trucking, financial services, and natural gas, ultimately provided an important boost to productivity growth by allowing businesses in those industries to operate with fewer constraints and more flexibility.[50]

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46 Fishlow (2000) and Mowery and Rosenberg (2000) also note the importance of intersectoral linkages between new technologies and other industries. 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 and the creation of new industries.

47 Fishlow (2000).

48 Engerman and Sokoloff (2000). 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.

49 For a discussion of patent policy in the context of financial market innovations, see Ferguson (2003).

50 See Winston (1998) for a summary of the evidence.

In a different vein, one must note the 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. For example, the tariffs that protected domestic markets from foreign competition in the 1800s are viewed by some observers as having provided manufacturers the opportunity to expand more rapidly.[51] However, even then, the American economy benefited considerably from free trade in intellectual property by exploiting technologies that had been invented abroad. Moreover, the experience of other periods of American history demonstrates that protectionist measures are not an effective means of promoting the diffusion of technology in a more developed economy. The detrimental economic effects associated with the passage of the Smoot-Hawley tariffs in 1930 provide one important example. And, in the post-World War II period, the relaxation of trade restrictions opened up important foreign markets to the new products being developed by U.S. corporations. More generally, 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.

Another lesson from past productivity booms is that the willingness of investors to hold securities is crucial for firms to raise the working capital they need to take advantage of the productivity potential of new technologies. For instance, as I noted earlier, 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. 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 extremely important, and a crucial aspect of this regulation has been the requirement that firms provide information that is extensive, accurate, and interpretable in a straightforward manner.

Government involvement in providing broad access to education has also played an important role in stimulating economic growth by continually improving the ability of the workforce to adapt to technical change. In the past, a basic facility for reading and arithmetic were essential to workers in a wide range of occupational settings, and American schools effectively provided these skills to our youths. In the economy of the future, the educational requirements of the population will be even greater. Not only will workers need basic skills in math and language, but they also will increasingly require knowledge of basic and applied science - as well as the ability to acquire new skills when required by their jobs. As a result, continued public recognition of the value of education as well as ongoing efforts to ensure widespread access to a high caliber of schooling at all levels will be indispensable.

Of course, I would be remiss if I did not also comment on the importance of sound macroeconomic policies in promoting long-run economic growth. Evidence clearly points to a correlation between low inflation and strong productivity growth. And while it is difficult to identify a strong causal relationship between a healthy economy and productivity, a couple of casual empirical observations are suggestive of a link. First, the number of patent applications tends to be higher in good economic times than during recessions.[52] If patenting is a valid measure of technological change, such a correlation suggests that innovation is stimulated by healthy economic conditions. Second, and perhaps more important, 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 the robust profit opportunities and lower uncertainties afforded by sustainable economic growth and low inflation.

Why do productivity booms end?

To complete my discussion, I want to turn briefly to the question of why periods of strong trend productivity growth come to an end. Several hypotheses have been put forth, including (1) that successful new technologies eventually lead to financial imbalances and overinvestment associated with excess optimism, (2) that periods of strong productivity growth eventually run out of steam as the

[51] There is considerable debate on this issue. See Lipsey (2000) for a brief summary.

[52] 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.

productivity - increasing opportunities associated with new technologies are exhausted, and (3) that exogenous shocks 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. Regarding the first hypothesis, support can be found in the soaring stock prices of the late 1870s, the 1920s and the late 1990s, which in all three cases were coincident with a period of very rapid productivity growth and were followed (eventually) in the first two cases by a collapse in stock prices and economic depression. In contrast, the steady rise in equity values during the 1960s did not appear to be associated with the emergence of any significant financial imbalance, and the subsequent decline in stock prices in the mid-1970s may owe importantly to the failure of economic policy to react to the changing dynamics of the economy and thus to control inflation. Similarly, in certain industries - most notably automobiles and electric utilities - a speculative rise in capital spending during the 1920s arguably did result in a significant overbuilding of capacity by the end of that decade. But such instances are more difficult to find in the late 1800s and in the 1960s. And, while there does appear to have been an overinvestment in high-tech and telecommunications equipment in the late 1990s, the recent productivity data certainly do not suggest that this overinvestment has ended the current productivity boom.

The hypothesis that productivity booms end when innovation and technical change levels off is difficult to test for the 1800s and early 1900s because of a lack of data. Arguments along this line, which surfaced to explain the productivity slowdown of the 1970s, pointed to the deceleration in the growth of research and development (R&D) spending in the late 1960s as evidence. However, Griliches (1988) has argued convincingly that this shortfall in R&D spending was not of sufficient magnitude to contribute very much to the productivity slowdown. But, even if the notion that technological innovations are eventually exhausted is valid, we have no evidence that this 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.

Finally, some role for exogenous shocks is also evident in past episodes, depending on how broadly one defines an exogenous shock. The 1973 oil shock is perhaps is the most convincing example, although the extent to which this ended the "golden era" is still the subject of much discussion. In addition, the bank panic of 1893 is viewed by some as an important contributor to the depression of the 1890s; however, whether this event is an exogenous shock or an indication of earlier economic excess (as in 1929) is debatable. Of course, we have also experienced significant exogenous shocks in recent years - including 9/11, the Iraq conflict, and a variety of corporate scandals. It is encouraging that the economy seems to have successfully weathered these recent shocks with no significant harm to productivity growth.

Conclusion

All of us as government economists, policymakers, and citizens have a stake in learning the lessons from past productivity booms. As I have said, productivity improvements translate directly into improvements in the standard of living. Economists will continue to debate the relative importance of various factors underlying productivity growth. But our experience in the United States clearly suggests that periods of relatively rapid trend 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. Productivity booms in the United States have been of varying duration, but we have seen two of them last as long as twenty years. We do not know definitively what brings these booms to an end. In our experience, however, periods of elevated increases in trend productivity are best fostered in an environment of economic and personal freedom and government policies that are focused on erecting sound and stable macroeconomic conditions that are most conducive to private-sector initiative.

US Productivity growth, 1873-2003

(Average annual percent change)

Period	Labor	Multifactor	Capital deepening and other[1]
1873-2003	2.0[2]	1.3[3]	0.7[3]
Episode I 1873-90	2.6	0.9	1.7
1890-1917	1.5	0.8	0.7
Episode II 1917-27	3.8	2.8	1.0
1927-48	1.8	1.7	0.1
Episode III 1948-73	2.9	1.9	1.0
1973-95	1.4	0.4	1.0
Episode IV 1995-2003	2.9[2]	1.0[3]	1.6[3]

[1] Includes changes in labor composition. [2] Based on data through 2003:Q3. [3] Based on data through 2001.

Source: Kendrick (1961) and U.S. Bureau of Labor Statistics.