Congressional Research Service

Report RL32456

Productivity: Will the Faster Growth Rate Continue?

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October 5, 2007

Abstract. The recent pickup in productivity is at least in part attributable to the rapid rate of decline in the prices of computers and other IT equipment. An important factor in those price declines has been innovation in the manufacture of microprocessors. As computer prices have fallen, their use has become much more widespread. Because of falling prices it has become profitable to put computers to uses with smaller and smaller returns. There is also the prospect that it may take firms a considerable amount of time to adapt the way they do business to take advantage of their investments in IT equipment. As was the case with other historic technological advances, the productivity gains attributable to investments in IT equipment may ripple through the economy for some time.

Order Code RL32456

CRS Report for Congress

Productivity: Will the Faster Growth Rate Continue?

Updated October 5, 2007

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Prepared for Members and Committees of Congress

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Summary

While policymakers have at least some direct or indirect influence over many economic variables, productivity growth may be among those that remain relatively removed from the influence of deliberate economic policy. Although many policy proposals are advocated on the grounds that they will help boost productivity, it may be that productivity growth rates have a greater influence on policy than policy does on the growth of productivity. It seems that variations in the productivity growth rate are so incompletely understood that there is no clear consensus among economists about the best way for policymakers to promote it.

Since the mid 1990s productivity growth appears to have accelerated. This is unusual in a mature economic expansion, which has suggested to more than a few observers that it was not just a short-term phenomenon, but rather a sign that there was an increase in the long-term economic growth rate.

An important question for policymakers is how long this surge in productivity growth will continue. Higher productivity growth means higher real incomes, which in combination with progressive income tax rates yields higher federal revenues. As long as Social Security operates on a pay-as-you-go basis, productivity growth also extends the date of reckoning as far as the trust fund balances are concerned, because the incomes of those paying Social Security taxes will grow more rapidly than the benefits. Whether productivity growth continues at the rate it did in the late 1990s is a critical concern for those making and using long-term economic forecasts.

Productivity is a highly cyclical variable, so that assessing its rate of growth at any single point in time requires knowing the particular stage of the business cycle. However, it is the long run trend rate of growth of productivity that is of particular interest because that is the source of rising standards of living. Following the business cycle peak in the fourth quarter of 1973, productivity growth slowed substantially. Unfortunately, that slowdown remains poorly understood, which makes it difficult to design policies that might promote productivity growth.

The recent pickup in productivity is at least in part attributable to the rapid rate of decline in the prices of computers and other IT equipment. An important factor in those price declines has been innovation in the manufacture of microprocessors. As computer prices have fallen, their use has become much more widespread. Because of falling prices it has become profitable to put computers to uses with smaller and smaller returns. There is also the prospect that it may take firms a considerable amount of time to adapt the way they do business to take advantage of their investments in IT equipment. As was the case with other historic technological advances, the productivity gains attributable to investments in IT equipment may ripple through the economy for some time. This report will be updated as economic developments warrant.

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Introduction

Of all the economic variables policymakers track, productivity growth may be one of the most important, at least over the long run, because it determines the rate of improvement in our national standard of living. Economy-wide increases in productivity indicate increases in real production and incomes, which have been achieved without an increase in work. Consumers can buy more of those goods and services (or leisure) that make their lives easier or more enjoyable. Even when productivity growth is limited to certain industries, everyone benefits from the lower prices (or the improved quality) for those goods and services.

While policymakers have at least some direct or indirect influence over many economic variables, productivity growth may be among those that remain relatively removed from the influence of deliberate economic policy. Although policy proposals may be represented as promoting productivity growth, productivity growth may have a greater influence on policy than policy does on the growth of productivity. It seems that variations in the productivity growth rate are so incompletely understood that there is no clear consensus among economists how policymakers might go about promoting it.

Nonetheless, productivity growth rates do have important consequences for policymakers. The budget process, for example, typically looks at least five, if not 10, years ahead in setting spending and tax policies. With respect to Social Security, the time frame is even longer. Over such an extended period of time, some insight into the outlook for productivity growth is critical to projecting other economic variables and establishing an economic baseline on which to base budget decisions. Without at least some understanding of underlying factors, projections of productivity may simply reduce to quantifying forecaster optimism.

Between 1973 and 1995, productivity growth was sluggish compared to what it had been during the 1960s. In 1995, productivity growth picked up. That it happened well into an economic expansion was unusual, and it raised hopes that it was more than temporary and promised a durable increase in the rate of growth. This report examines both the cyclical and long-run characteristics of productivity growth, discusses continuing efforts to explain the acceleration in productivity growth, and considers whether the faster growth rate can be expected to continue.

What is Productivity?

Productivity is a ratio. It is a measure of the quantity of output produced relative to the amount of work required to produce it. Most often it is expressed as the ratio of some measure of inflation-adjusted output to the number of labor hours involved. Mathematically, it looks something like this:

$$productivity = \frac{output}{hours}$$

Rearranging the terms can help illustrate the significance of productivity:

$$output = productivity \times hours$$

This shows that total output is a function of both work and productivity. Any increase in output must therefore come about as the result of increases in either hours worked or productivity.

In the short run, hours worked may vary over the business cycle as the unemployment rate rises and falls. Beyond that, hours worked may vary somewhat over time as the proportion of the population in the labor force changes. But, in the long run, hours is primarily determined by population growth. Output growth is an important policy goal, but if it only comes by increasing hours worked then living standards are unlikely to improve.

When the economy is at full employment, the combined growth rates of labor and its productivity represent a sort of speed limit. Sustained economic growth above that limit is considered likely to result in an accelerating rate of inflation. That is another reason why it is important for policymakers to be aware of productivity growth trends.

The Difficulty of Projecting Productivity

To make long-run projections of output, forecasters must estimate what productivity growth will likely be over the forecasted period. However, the study of productivity has not advanced to the point where it can be projected based on what is known now about economic conditions. Most forecasts project productivity growth to continue at its current trend rate of growth.

The current trend rate of productivity growth can be difficult to discern. Usually, trend rates of growth in productivity are measured over the entire course of a business cycle to control for cyclical variability in the rate of productivity growth. The trend rate is thus determined by comparing productivity at successive business cycle peaks. But, depending on the length of those cycles, that may mean estimates of the trend rate of growth of productivity are based on somewhat dated information. It can take a considerable length of time before a change in the trend rate of growth is fully appreciated.[1]

Although it is now clear that productivity growth picked up beginning in 1995, it was some time before it was thought to be part of a potentially durable shift in the long-run rate of productivity growth. Most economic forecasters, including the Congressional Budget Office and the Office of Management and Budget, underpredicted real economic growth by an average of about 2 percentage points in each of the fours years after 1995.[2]

Now that the acceleration in productivity has outlived the last expansion and seems to be continuing into the present one, there is growing confidence it will persist. Whether that confidence is misplaced, only time will tell.

The Cyclical Nature of Productivity

In the short run it can be difficult to tell whether a change in the rate of productivity growth is temporary or indicative of a change in the long-run trend. To economists, productivity's significance has more to do with the long run, and so variations in its long-run trend and the factors that influence it are the focus of considerable research. Productivity is a cyclical variable, and tends to fluctuate in somewhat predictable ways over the course of the business cycle. Understanding those cyclical patterns is necessary to any analysis of productivity data.

Although each business cycle has unique aspects, there are certain tendencies that characterize them. One of those tendencies is for productivity growth to be *procyclical*. In a recession, productivity tends to decline, or grow less rapidly. As the recession ends, and the economy begins to expand, productivity growth usually picks up.

At the beginning of an economic contraction, demand for goods and services declines but firms may be slow to lay off workers both because they may have invested a considerable amount of time and money in their recruitment and training, and because there are costs associated with laying those workers off and then rehiring them when business recovers. The other input to production, physical capital, is relatively fixed in the short run. So, at the beginning of an economic downturn, output tends to fall more rapidly than either labor or capital, and so measured productivity declines.

If the contraction continues and production falls enough, firms will begin to lay off workers. At first, they will tend to be those most recently hired with the least amount of training and who were relatively less productive than those hired before.

[1] The last two complete business cycles exceeded 100 months measured from peak to peak.

[2] CRS Report RL30239, *Economic Forecasts and the Budget*, by Brian W. Cashell.

Reducing the quantity of labor employed tends to moderate any initial deceleration in measured productivity growth.

As the contraction comes to an end and the economy begins to expand again, firms can increase their output initially by putting idle capital back to work and taking advantage of any under-utilized labor already on hand. This increase in output with little or no increase in hours worked is reflected in relatively rapid productivity growth. Once increasing demand can no longer be satisfied with existing capacity, additional labor will be added. Those hired first will tend to be those relatively more experienced. As more and more labor is hired, the contribution to output of each additional hire tends to drop. As the expansion ages, productivity growth slows from the rates earlier on in the expansion.

The general tendency is thus for productivity growth to decline during contractions and increase in expansions. Other things being equal, productivity growth is likely to be faster in the early stages of an expansion than it is after the economy has regained full employment.

Measurement Issues

Productivity is a ratio of the quantity of output produced to the quantity of inputs used in its production. An increase in the quantity of output with no increase in hours worked would be an increase in productivity. As long as output is rising faster than the contribution of labor and capital, measured productivity will rise.

The most commonly cited measure of productivity published by the federal government is average labor productivity. It is published quarterly by the Bureau of Labor Statistics of the Department of Labor (BLS). The measure of output used by BLS in its calculation is based on data from the national income and product accounts published by the Bureau of Economic Analysis (BEA) of the Department of Commerce. Labor productivity is measured in terms of average output per hour. It is a ratio of the quantity of output to the hours of work done. If the quantity of output rises by the same proportion as the amount of work, then the economy is only producing more either because there are more workers, or workers are putting in longer hours, and there is no productivity growth. If output rises faster than hours worked, labor productivity is also increasing.

Problems in Measuring Real Output

Production of goods and services is necessarily measured in terms of dollar values because that is the only unit of measure common to all of the goods and services produced. The dollar value of output, however, reflects not only the quantity of goods and services produced, but also their prices. The dollar value of output will rise with in increase in the quantity of goods and services produced, but it will also rise with an increase in their prices. Distinguishing between changes in output that are "real" (i.e., indicative of changes in quantity), and changes that are due only to variations in the general price level is a difficult problem.

Productivity measures are based on inflation-adjusted measures of output. The way in which price change is measured can thus affect measures of productivity growth. If existing price indexes understate the rate of inflation, that will cause estimates of productivity growth to be overstated.

Few goods or services stay the same from year to year. Over time, most products acquire new characteristics that make it difficult to compare them with earlier models. An increase in the price of a car, for example, may reflect rising prices throughout the economy, but it may also reflect new features such as catalytic converters or airbags. Ideally, those price increases due to the addition of these new characteristics would not affect the price index for cars. Even though the same number of cars might be sold in successive periods, the newer model car might provide a better (e.g., safer or less polluting) service over its useful life. A more difficult problem is the introduction of an entirely new product because there is no price from an earlier period with which to compare the introductory price.

Of all the goods and services produced, computers may be changing the most rapidly from year to year. The prices of computers have been falling, and their performance has been improving dramatically. Rather than simply track change in the price of a "computer" from one year to the next, the BEA attempts to track changes in the price of "computing power."[3] That means that it tries to take into account changes in memory, processing speed, and other features when estimating price change in successive models of computers.

Some sectors of the economy may be easier to measure than others. In the case of manufactured goods there is at least a tangible product that can be counted even though there may be difficulties in assessing changes in its quality or other characteristics. In the case of services, it can be difficult even to define what is being produced. Take medical care, for example. In the case of physician services, what should be measured as production, the number of office visits per hour? Should success at treating various ailments be taken into account?

Some have argued that because the service sector accounts for a growing share of total national output, and because it is more difficult to measure productivity in the service sector, that overall measures of productivity have become more prone to error. At one time it was suggested that at least part of the slowdown in productivity growth that began, by most accounts, in 1973 may have been due to measurement problems associated with the increased size of the service sector.[4] More recent evidence suggests that is unlikely to have been the case. Those sectors considered to be harder to measure account for some of the larger productivity gains since 1995.[5]

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[3] J. Steven Landefeld and Bruce T. Grimm, "A Note on the Impact of Hedonics and Computers on Real GDP," *Survey of Current Business*, Dec. 2000, pp. 17-22.

[4] Zvi Griliches, "Productivity, R&D and the Data Constraint," *American Economic Review*, vol. 84, issue 1, Mar. 1994, pp. 1-23.

[5] Robert J. Gordon, *Recent Productivity Puzzles in the Context of Zvi Griliches' Research*, paper presented to meetings of the American Economic Association, Jan. 5, 2002, 17 pp.

Growth in Labor Productivity

How does productivity growth in the economic expansion of the 1990s compare with those of the past? **Table 1** presents data for annual rates of growth in *labor* productivity between successive business cycle reference dates for the post-war era.[6]

Two observations are apparent from the data in the table. First, there is clearly a tendency for productivity growth to be procyclical. That is to say that productivity growth is higher during expansions (trough to peak) than during contractions (peak to trough). Moreover, productivity growth was faster in the first year of each expansion (with the exception of the one-year expansion of 1980-1981) than it was in the last year. Second, it is clear from the data that, following the business cycle peak in the fourth quarter of 1973, productivity growth was quite a bit slower than it had been in prior years.

Table 1. Growth in Output per Labor Hour, Nonfarm Business Sector

Business Cycle Reference Dates (year and quarter)			**Average Annual Rate of Growth from:** (percent)		
peak	trough	peak	peak to trough	trough to peak	peak to peak
1948:4	1949:4	1953:3	3.7	3.4	3.5
1953:3	1954:2	1957:3	0.6	2.3	2.0
1957:3	1958:2	1960:2	0.9	2.9	2.3
1960:2	1961:1	1969:4	0.2	2.9	2.7
1969:4	1970:4	1973:4	1.5	3.0	2.9
1973:4	1975:1	1980:1	2.6	1.5	1.1
1980:1	1980:3	1981:3	-1.5	2.2	1.0
1981:3	1982:4	1990:3	-0.6	2.0	1.6
1990:3	1991:1	2001:1	-1.0	2.1	2.0

Sources: National Bureau of Economic Research; Department of Labor, Bureau of Labor Statistics.

To separate changes in long-term trends from those changes that reflect more variable short run economic conditions, analysts often compare data from similar points in successive business cycles. A look at the peak-to-peak rates of growth in

[6] These data reflect productivity in the nonfarm business sector. The business cycle reference dates use here are those established by the National Bureau of Economic Research (NBER), and indicate the beginnings and endings of periods of economy-wide expansions and contractions.

productivity for past business cycles reveals that productivity growth fell by about half after 1973.

The Post-1973 Slowdown in Productivity Growth

For much of the post-World War II era, the United States experienced relatively rapid rates of productivity growth. Between the fourth quarter of 1948 and the fourth quarter of 1973, output per labor hour in the nonfarm business sector grew at an annual rate of 2.7%. Between the fourth quarter of 1973 and the fourth quarter of 1995, that rate fell to 1.5% per year. Most economists point to 1973 as the beginning of an extended period of slower productivity growth. That drop in the rate of productivity growth has been the focus of much economic research. Thus far, the slowdown remains poorly understood.

The prime suspect in that slowdown, at least initially, was the OPEC oil price hike, which in 1973 roughly doubled the price of crude oil. The mere coincidence of the productivity slowdown and the rise in price of a major input to the production of goods and services motivated research into the connection. The theory was that, because of higher energy costs, much of the existing capital stock which relied on energy to contribute to output became obsolete.[7]

Subsequent experience, however, cast doubts on the significance of the coincidence. Between 1979 and 1981, oil prices doubled again, and then in 1986 the price of oil fell by nearly half. That only one of these large oil price changes was associated with a shift in the trend rate of growth in productivity suggested that if there was a single factor to blame for the 1973 slowdown, it was likely to be found elsewhere.

Another potential cause for the post-1973 slowdown was spending on research and development (R&D). Griliches found that R&D spending, as a percentage of GDP, declined beginning in the mid-1960s.[8] The timing of the decline would seem to implicate it, but it is hard to make a strong case out of a single instance. Moreover, other countries also experienced a decline in productivity growth without R&D spending having dropped.

Griliches also pointed out that, in the 1970s, the number of patents granted in the United States declined. That resulted in a drop in the number of patents per dollar of R&D spending. Griliches suggested that decline in the number of patents per dollar of R&D spending may have been evidence of diminishing returns to R&D spending, and he wondered if there might be a sort of technological frontier near which opportunities for invention become relatively scarcer.

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[7] Martin Neil Baily, "Productivity and the Services of Capital and Labor," *Brookings Papers on Economic Activity 1*, 1981, pp. 1-50.

[8] Zvi Griliches, "Productivity, R&D, and the Data Constraint," *American Economic Review*, vol. 84, no. 1 (Mar. 1994), pp. 1-23.

Maddison examined a number of factors in an effort to account for the role each one may have played in the slowdown.[9] Maddison was able to "explain" only 41% of the total deceleration in output growth. Of 14 separate factors, the most important was found to have accounted for less than one-seventh of the slowdown.

Because the slowdown in productivity has been dated to a single point in time, it was suspected that a single cause for the slowdown might be found. Identifying a single cause would have been more satisfying in that policy measures might have been designed to reverse it. If the slowdown had affected different industries more or less equally, that might have favored arguments that a single cause was responsible. However, when productivity trends were examined for individual industries, some were found to have fared well in comparison with others.[10]

Gordon offered a slightly different perspective on the post-1973 slowdown. He maintained that, rather than trying to explain why productivity growth slowed in the 1970s and 1980s, the focus should instead be on why it was so rapid earlier.[11] Gordon argued that, in the 1970s, productivity growth simply fell back to its long-run trend rate, and that the growth experienced earlier in the century was unusually rapid due to a number of technological advances. Among the advances he cites are the spread of electric motors, the internal combustion engine, and the telephone and its derivatives. Gordon argues that these innovations had a much greater economic effect than the electronic computer. He goes on to suggest that the economy may be on a long-run curve of diminishing returns to technological advancement, and that the various modifications and improvements to devices such as computers are less important than their introduction.

Accounting for Economic Growth

Thus far, economic growth has been explained as the sum of the growth rates of labor and labor productivity. But, labor is not the only factor of production, so that explanation remains incomplete. Most economic textbooks present a basic overview of the theory of economic growth that is known as the "neoclassical" model. In this model, output is explained as the result of a combination of not just labor, but also capital and "technology."

In this model, the size of the capital stock is determined by the saving rate and technology is treated as "exogenous," which is economic jargon for a variable which does not react to the internal influences of the variables in the model but rather is

[9] Angus Maddison, "Growth and Slowdown in Advanced Capitalist Economies," *Journal of Economic Literature*, vol. 25, no. 2 (June 1987), pp. 649-681.

[10] Robert J. Gordon, *Problems in the Measurement and Performance of Service-Sector Productivity in the United States*, National Bureau of Economic Research, Inc., Working Paper no. 5519, Mar. 1996.

[11] Robert J. Gordon, "Comments," in Ben S. Bernanke and Julio J. Rotemberg, eds., NBER *Macroeconomics Annual 1996*, MIT Press, pp. 259-267.

external to it and independent.[12] Labor productivity growth is thus explained by the increasing amount of capital per worker and technological progress.

In an effort to match data to theory, BLS produces a set of productivity measures that account for the contribution of both labor and capital in production. Multi-factor productivity measures attempt to account for both physical and human capital accumulation.[13] Accounting for more of the inputs to production reduces the amount of growth that remains unexplained. **Table 2** compares multi-factor productivity and average labor productivity trends for selected periods.

Table 2. Productivity Growth Rates, Nonfarm Business

	Annual Rate of Change in:	
	Average Labor Productivity	Multi-Factor Productivity
1948 to 1973	2.8	1.9
1973 to 1995	1.4	0.4
1995 to 2001	2.5	1.0
1995 to 2002	2.8	1.1
1995 to 2003	2.9	1.3
1995 to 2004	2.9	1.4
1995 to 2005	2.8	1.5
1995 to 2006	2.6	1.4

Source: Department of Labor, Bureau of Labor Statistics.

Both measures show that after 1973 productivity growth slowed, and that after 1995 it accelerated. In the case of multi-factor productivity, growth is faster than it was between 1973 and 1995 but still below what it was before 1973.[14] The growth rate of average labor productivity is now close to what it was prior to 1973. Those two years of faster growth may be related to the usual cyclical pattern.

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[12] Robert Solow, "Technological Change and the Aggregate Production Function," *Review of Economics and Statistics*, vol. 39 (Aug. 1957), pp. 312-320.

[13] Because of the requirement for data on the capital stock, multi-factor productivity data are only available annually.

[14] Multi-factor productivity data are only available through 2001. Multi-factor productivity data are not usually as up-to-date as labor productivity because of the need to collect data on the capital stock.

Computers and Productivity Growth

Robert Solow, a major contributor to the theory of economic growth, is often quoted for his remark that the effect of computers can be seen everywhere but in the productivity statistics.[15] Through the 1980s and early 1990s, there seemed to be no big payoff from the growing stock of computers. That presented a puzzle to those who expected significant returns.

It is now believed that computers have had much to do with the acceleration in productivity growth since the mid-1990s. Whether that is the case and how computers have affected productivity growth are important in trying to assess how durable the acceleration will prove to be.

It is getting to the point where consumers expect the rapid pace of innovation in the manufacture of computers to continue. It is also widely assumed that the speed and memory capacity of those computers will continue to improve at a steady pace. This rapid rate of technological advance in the development and manufacture of computers was predicted in 1965 by Gordon E. Moore, one of the co-founders of Intel Corporation.[16] Specifically "Moore's Law" predicted that the number of transistors that could be put on a computer chip would double every 18 months. Whether that prediction was a self-fulfilling prophecy may be open to question, but the fact is that the pace of technological advance in the manufacture of computers has vindicated Moore's Law over time.

Because of the rapid innovation in the production of computer chips, the prices of computers, as well as other goods related to information processing and communications, sometimes referred to collectively as information technology (IT), have been falling steadily for some time. **Figure 1** shows the chain-weighted price index, published by BEA, for computers and peripheral equipment from 1959 through the middle of 2007. Because the changes are so large the chart is plotted on a logarithmic scale. Using a logarithmic scale has the added advantage in that the slope of the line indicates the rate of change in the variable. In this case, the rate of change in computer prices has been fairly steady for a long time. Between 1959 and 1995, computer prices fell at an average annual rate of 17.2%, and between 1995 and 2007 prices fell at an annual rate of 16.4%.

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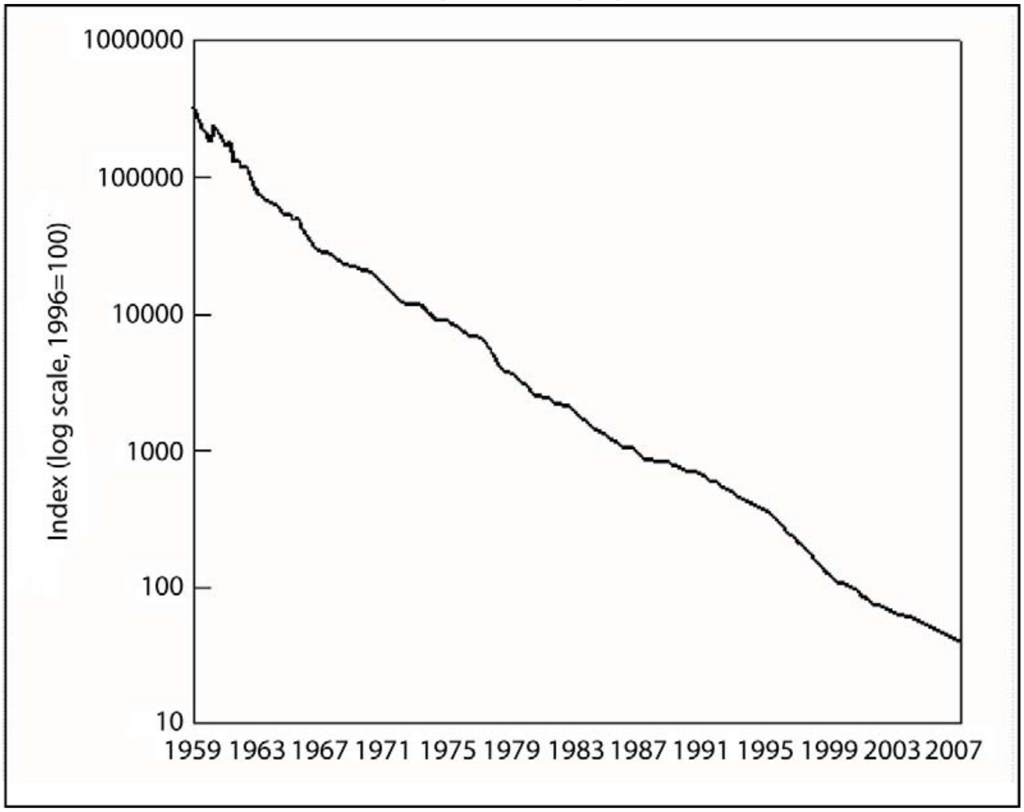
[15] Robert Solow, "We'd Better Watch Out," *New York Times Book Review*, July 12, 1987, p. 36.

[16] Gordon E. Moore, "Cramming more components onto integrated circuits," *Electronics*, vol. 38, no. 8, Apr. 19, 1965. See also the Intel website at [http://www.intel.com/technology/mooreslaw/index.htm].

Figure 1. Chain-Weighted Price Index for Computers and Peripheral Equipment



Source: Department of Commerce, Bureau of Economic Analysis.

These price declines reflect substantial improvements in the quality of computers. BLS has developed a procedure for estimating price indexes for goods whose characteristics are changing rapidly. These are referred to as "hedonic" price indexes. Hedonic price indexes attempt to estimate a statistical relationship between prices and a set of characteristics, such as memory and processor speed.

These price indexes are important to the measurement of productivity, because estimating price change is necessary to estimating change in real output and thus productivity. If the rate of price decline in computers is overestimated, then measures of productivity will be overstated. Most studies estimate that, in the late 1990s, prices for personal computers alone fell at an annual rate of somewhere between 30% and 40%.[17]

Rapid declines in computer prices have, not surprisingly, stimulated a surge in investment. **Figure 2** shows the chain-linked quantity index for investment in computers and related equipment from the national income and product accounts (NIPA). Although data date back to 1959, production of computers was negligible until the 1980s. Thus, even though real output of IT equipment was increasing rapidly, it did not account for a very large share of total output until recently.

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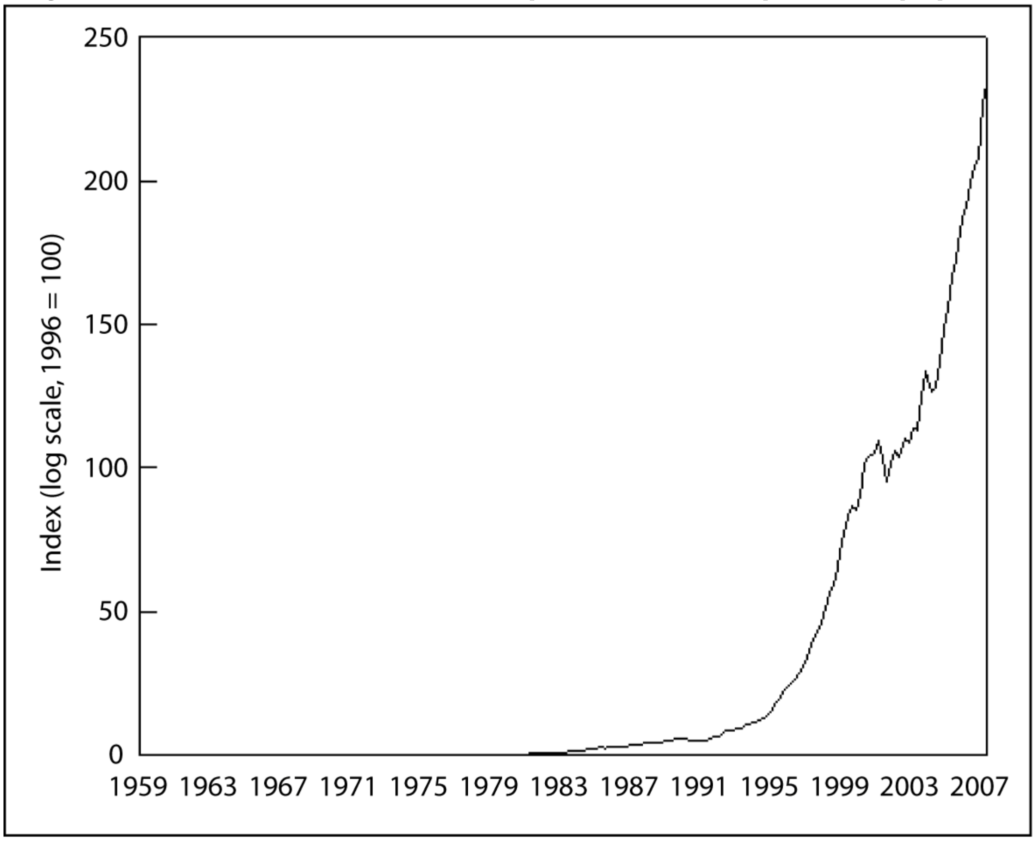
[17] J. Steven Landefeld and Bruce T. Grimm, "A Note on the Impact of Hedonics and Computers on Real GDP," *Survey of Current Business*, Dec. 2000, pp. 17-22.

Figure 2. Real Investment in Computers and Peripheral Equipment



Source: Department of Commerce, Bureau of Economic Analysis.

Computers have affected growth in productivity in at least two ways. First, there has been rapid productivity growth in the production of computers which, as computers accounted for an increasing share of total production, tended to raise the overall measure of productivity growth. Second, the sharp drop in computer prices has stimulated increased investment in computers, which has contributed to an increase in the overall amount of capital available to the workforce. This is often referred to as "capital deepening." Increases in the capital stock generally tend to raise worker productivity.

Accounting for the Role of Computers in the Post-1995 Acceleration in Productivity Growth

Prior to the recent acceleration in productivity growth, most analyses found that computers had not yielded much benefit. One reason for that is that, until recently, computers accounted for a relatively small share of the total capital stock.[18]

[18] Stephen D. Oliner and Daniel E. Sichel, "Computers and Output Growth Revisited: How Big is the Puzzle?" *Brookings Papers on Economic Activity*, 2:1994, pp. 273-334.

But, that view has now changed. Although perhaps not yet embracing all of the claims of proponents of a "new economy," economists are encouraged that the acceleration in productivity growth of the late 1990s may mean that the economy is on a higher growth path and that computers have had a lot to do with it.

Two widely cited studies, discussed below, found considerable evidence that the computer, or more generally IT equipment, is behind most of the recent acceleration in productivity growth. There is also evidence of a modest "spillover" into other sectors of the economy. In other words, investment in computers can raise the productivity of the workers who use them, but it may also lead firms to change the way they operate leading to further productivity gains.

The first study, by Oliner and Sichel at the Federal Reserve Board, found that of a 0.9 percentage point increase in the growth rate of total factor productivity from the first half of the 1990s to the second half, all of it could be accounted for by advances in the production of computers themselves and the also by the use of those computers.[19] **Table 3** presents a breakdown of Oliner and Sichel's accounting for productivity growth for selected periods since 1974.

Table 3. Contributions to Productivity Growth

	1974-1990 (1)	1991-1995 (2)	1996-2001 (3)	Change (3) - (2)
Growth rate of labor productivity	**1.36**	**1.54**	**2.43**	**0.89**
Contributions from:				
Capital Deepening	**0.77**	**0.52**	**1.19**	**0.67**
Information technology capital	0.41	0.46	1.02	0.56
Other capital	0.37	0.06	0.17	0.11
Labor quality	**0.22**	**0.45**	**0.25**	**-0.20**
Multi-factor productivity	**0.37**	**0.58**	**0.99**	**0.41**
Semiconductors	0.08	0.13	0.42	0.29
Computer hardware	0.11	0.13	0.19	0.06
Software	0.04	0.09	0.11	0.02
Communication equipment	0.04	0.06	0.05	-0.01
Other nonfarm business	0.11	0.17	0.23	0.06

Source: Oliner and Sichel.

[19] Stephen D. Oliner and Daniel E. Sichel, *Information Technology and Productivity: Where Are We Now and Where Are We Going?* Board of Governors of the Federal Reserve System, May 2002, 78 pp.

Oliner and Sichel found that of a 0.89 percentage point increase in average labor productivity between the early and late 1990s, 0.56 was due to increased investment in IT related capital (an increase from 0.46 to 1.02), and 0.35 was due to increased productivity in the production of IT equipment (an increase from 0.26 to 0.61 in the combined computer and semiconductor sectors). Thus, the contribution of IT equipment to the increase in productivity was greater than the overall increase. Oliner and Sichel also found that labor quality's contribution to productivity growth declined during the 1990s. That is likely related to cyclical factors as the unemployment rate fell and the available pool of skilled workers shrank.

Oliner and Sichel, using an economic model, attempted to assess the implications of recent developments in the technology sector for prospects for continued rapid productivity growth. They conclude that productivity growth is likely to fall somewhere in the range of 2% - 2¾% over the next 10 years.

A second study, by Jorgenson, Ho, and Stiroh, came to similar conclusions.[20] **Table 4** presents the results of their analysis.

Table 4. Sources of Productivity Growth

	1959-1973 (1)	1973-1995 (2)	1995-2001 (3)	Change (3) - (2)
Growth rate of labor productivity	2.63	1.33	2.02	0.69
Contributions from:				
Capital Deepening	1.13	0.80	1.39	0.59
IT Capital Deepening	0.19	0.37	0.85	0.48
Other Capital Deepening	0.95	0.43	0.54	0.11
Labor Quality	0.33	0.27	0.22	-0.05
Total Factor Productivity	1.16	0.26	0.40	0.14
Information Technology	0.09	0.21	0.41	0.20
Non-information Technology	1.07	0.05	-0.01	-0.06

Source: Jorgenson, Ho, and Stiroh.

According to Jorgenson, Ho, and Stiroh's estimates, of a 0.69 percentage point rise in average labor productivity growth during the 1990s, increased investment (capital deepening) accounted for 0.59 percentage point, and improved productivity in the IT sector itself contributed another 0.20 percentage point of the acceleration.

[20] Dale W. Jorgenson, Mun S. Ho, and Kevin J. Stiroh, *Lessons From the U.S. Growth Resurgence*, paper prepared for the First International Conference on the Economic and Social Implications of Information Technology, held at the U.S. Department of Commerce, Washington, DC, on Jan. 27-28, 2003, 28 pp.

The evidence suggests that increased productivity in the sector producing IT equipment has had a modest direct effect on total factor productivity. By far the more important factor has been the declining price of IT equipment stimulating a surge in investment and increasing the size of the capital stock.

Remember that total factor productivity measures changes in output that are not accounted for by changes in economic inputs such as labor and capital. There is no doubt that computers are raising productivity of many firms, but, as long as economic statistics measure them correctly, the increased share of work computers do will not show up in increased multi-factor productivity because that measure of productivity tracks the increase in output not associated with the increase in investment in computers.[21] It is unclear whether computers have had any "spillover" effects on multi-factor productivity beyond their direct contribution to growth in output.

Some evidence suggests that those spillover effects — of computers on total factor productivity — are fairly small. Jorgenson and Stiroh found that those sectors of the economy that invest most heavily in computers and IT equipment, such as financial services, had among the lowest rates of productivity growth measured.[22]

Jorgenson, Ho, and Stiroh also estimated projections of growth in average labor productivity. They projected that productivity growth would range between 1.14% and 2.38% over the next decade, with a base case of 1.78%, just below the 1995 - 2001 rate of growth.

In another study, Robert Gordon found that most of the acceleration in labor productivity was attributable to capital deepening and faster productivity growth in the production of computers and IT equipment.[23] Of the roughly 0.2 percentage point increase in total factor productivity, most was accounted for by faster productivity growth in the manufacture of durable goods. That suggests that any spillover effects of computers on the overall economy were limited.

Is IT the Whole Story?

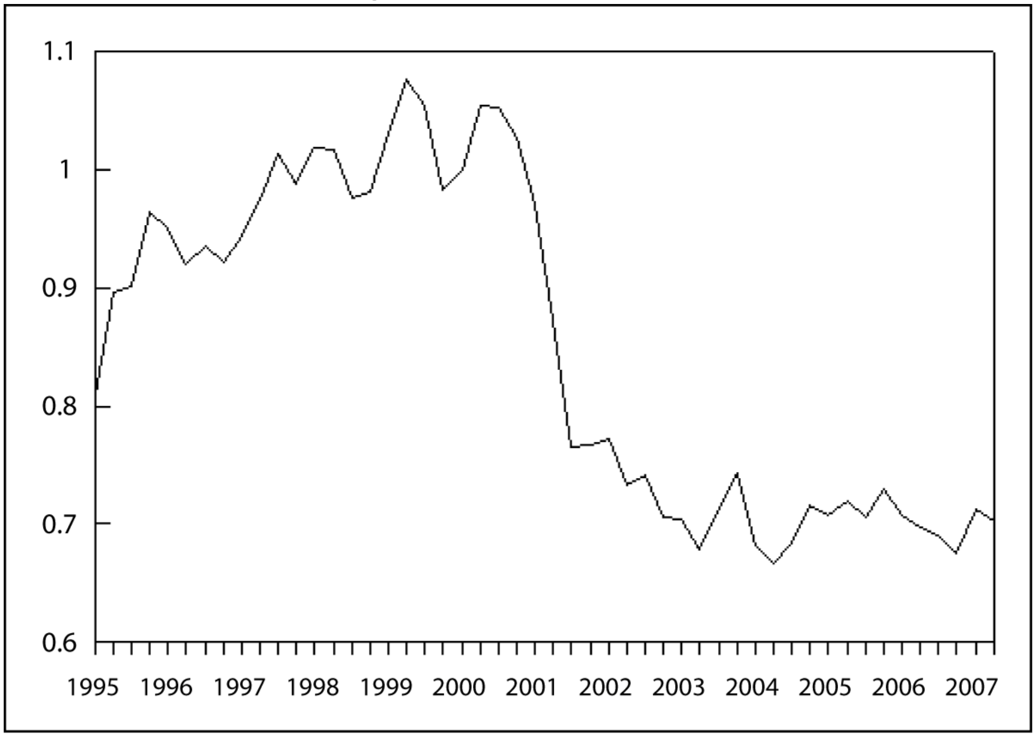
Since the publication of those studies attributing much of the acceleration in productivity growth to IT investments, there was a significant decline in the share of GDP allocated to IT investments. **Figure 3** shows investment spending as a percentage of GDP since 1995.

[21] Barry P. Bosworth and Jack E. Triplett, *What's New About the New Economy? IT, Economic Growth and Productivity*, Brookings Institution, Dec. 2000, 35 pp.

[22] Dale W. Jorgenson and Kevin J. Stiroh, "Raising the Speed Limit: U.S. Economic Growth in the Information Age," *Brookings Papers on Economic Activity*, 2000(1), vol. 2, pp. 125-212.

[23] Robert J. Gordon, *Technology and Economic Performance in the American Economy*, National Bureau of Economic Research, Working Paper no. 8771, Feb. 2002.

Figure 3. Investment in Computers and Peripheral Equipment as a Percentage of Gross Domestic Product



Source: Department of Commerce, Bureau of Economic Analysis.

Gordon suggests that the continuation of rapid productivity gains following the decline in spending on computers may mean that the earlier studies exaggerated the contribution of IT spending on the post-1995 acceleration in productivity growth.[24] Gordon argues that it is implausible that increased investment in IT equipment would have an immediate effect on productivity growth. Gordon points out that it took forty years for the benefits of electrification to be fully realized. Factories had to be reorganized to take advantage of electric power. In the same way, the introduction of computers has driven firms to change business practices. Those changes take time. But the reorganization, as well as worker training and other novel business practices made possible by the introduction of computers, may have contributed to productivity in ways that are difficult to measure.

One of the sectors of the economy that experienced relatively rapid productivity growth is retail trade. Fernald and Ramnath cite the particular example of so-called big-box stores that have become pervasive in retailing.[25] The success of those large scale retailers may have been made possible by the introduction of computers. Computers allowed those stores to manage sophisticated distribution networks and

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[24] Robert J. Gordon, "Exploding Productivity Growth: Context, Causes, and Implications," *Brookings Papers on Economic Activity*, 2:2003, pp. 207-298.

[25] John G. Fernald and Shanthi Ramnath, "The Acceleration in U.S. Total Factor Productivity after 1995: The Role of Information Technology," Federal Reserve Bank of Chicago *Economic Perspectives*, 1Q/2004, pp. 52-67.

improve inventory control, and by growing in size also benefit from economies of scale.

Baily also suspects that the contribution of IT investments to faster productivity growth might have been overstated.[26] He points out that prior to 1995, growth accounting was not especially helpful in explaining variations in productivity growth. Given the relatively small number of observations on which the studies linking IT investments to productivity are based they might still be treated with some skepticism. He argues that it might also be the case that the increase in IT spending was motivated by the acceleration in growth.

Nordhaus analyzed the contribution of what he called the "new economy" to the post-1995 acceleration in productivity growth.[27] The four industries included in his definition of the new economy are: industrial machinery and equipment, electronic and other electric equipment, telephone and telegraph, and software. He found that labor productivity in total non-farm business accelerated by 1.61 percentage points between the 1977-1989 period and the 1995-2000 period. Of that, the new economy industries contributed only 0.29 percentage point, or about a sixth of the total acceleration.

Nordhaus also calculated productivity growth for those industries whose production was "well measured." Well-measured industries included, agriculture forestry and mining; manufacturing; transportation and public utilities; wholesale trade; retail trade; and a small number of services. Nordhaus found that the productivity growth in the well-measured economy accelerated by 1.31 percentage points, less than the increase in total labor productivity. Nordhaus concludes that, while the new economy contributed, the rise in productivity growth was not limited to those firms but was widespread.

Will the Faster Productivity Growth Continue?

Perhaps the most important question for policymakers is whether or not the surge in productivity growth of the late 1990s will continue. Higher productivity growth means higher real incomes, which in combination with progressive income tax rates yields higher federal revenues. As long as Social Security operates on a pay-as-you-go basis, it also extends the date of reckoning as far as the trust fund balances are concerned because the incomes of those paying Social Security taxes will grow more rapidly than the benefits. Whether or not productivity growth

[26] Martin N. Baily, "Recent Productivity Growth: The Role of Information Technology and Other Innovations," Federal Reserve Bank of San Francisco *Economic Review*, 2004, pp. 35-41.

[27] William D. Nordhaus, "Productivity Growth and the New Economy," *Brookings Papers on Economic Activity*, 2:2002, pp. 211-265.

continues at the rate it did in the late 1990s is a critical concern for those making and using long-term economic forecasts.[28]

It now seems likely that most of the increase in productivity growth of the late 1990s was not just a cyclical variation, but rather faster productivity growth seems likely to persist. But there is still no guarantee.

The major difficulty in projecting productivity growth remains an imperfect understanding of past variations. Some of the sources of productivity growth are clearly understood. Increased investment and a growing capital stock raise labor productivity. Increased education and training also contribute. But aside from the contributions of human and physical capital, much less is certain. To a great extent, projections of productivity still reflect the optimism or pessimism of the forecaster.

It is clear however that the recent pickup in productivity is at least in part attributable to the rapid rate of decline in the prices of computers and other IT equipment. An important factor in those price declines has been innovation in the manufacture of microprocessors. Whether or not that rapid pace of innovation keeps up, and prices continue to fall will be important factors in future rates of productivity growth. However, ultimately there may be limits to the number of transistors that can be put on a single computer chip.

As computer prices have fallen, their use has become much more widespread. Because of falling prices it has become profitable to put computers to uses with smaller and smaller returns. But, as long as recent rates of innovation in the production of computers and IT equipment continue, productivity might at least be expected to continue growing more rapidly than it did between 1973 and 1995.

There is also the prospect that it may take firms a considerable amount of time to adapt the way they do business to take advantage of their investments in IT equipment. As was the case with other historic technological advances, the productivity gains attributable to investments in IT equipment may ripple through the economy for some time.

[28] Paul W. Blauer, Jeffrey L. Jensen, and Mark E. Schweitzer, Productivity Gains, How Permanent? Federal Reserve Bank of Cleveland *Economic Commentary*, Sept. 1, 2001.