

# National Productivity Statistics

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Roy H. Webb

**M**any people now enjoy levels of prosperity that would have been barely imaginable a few hundred years ago. That remarkable achievement can be viewed through the lens of productivity statistics that give quantitative estimates of output per unit of input. By studying productivity, analysts can improve their understanding of the causes of national prosperity and economic growth. Since different definitions of productivity are widely used, this article reviews the most important ones used in the United States. The article also contains a brief sketch of the historical behavior of productivity and then warns readers about potential pitfalls in using productivity statistics. Finally, the background material is used to address questions concerning the recent behavior of productivity statistics.

## 1. WHAT EXACTLY IS PRODUCTIVITY?

Simply stated, productivity is output per unit of input. Actually calculating a number can be somewhat more complicated. Suppose that we can agree that aggregate national output is adequately modeled by using a Cobb-Douglas production function

$$Y_t = A_t K_t^\alpha L_t^{1-\alpha}, \quad (1)$$

where  $Y$  is aggregate output,  $K$  is the capital stock,  $L$  is labor input,  $t$  is a time-period index,  $\alpha$  is a number between zero and one, and  $A$  will be discussed later. For national productivity statistics, an obvious starting point is to take an estimate of aggregate output such as real gross domestic product (GDP) from the National Input and Product Accounts (NIPAs). On the input side, the first

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requirement is to measure labor input, such as the number of workers or the number of hours worked.

The Bureau of Labor Statistics (BLS) currently publishes three categories of productivity estimates, which in terms of equation (1) are simply of the form  $Y/L$ . The most widely cited category is published quarterly and takes an output measure from the NIPAs for a large sector of the economy. *Business product* is the portion of real GDP produced by the business sector, and thus excludes production from the household sector, the foreign sector, and the government sector. *Nonfarm business*, naturally, is business product minus farm production. Product of *nonfinancial corporations* further excludes production by financial firms and by proprietorships and partnerships. Also, as part of its quarterly estimates, the BLS publishes productivity statistics for the manufacturing sector. In 1992, business product accounted for 76 percent of GDP, nonfarm business product was 75 percent of GDP, nonfarm nonfinancial corporate business product was 52 percent of GDP, and manufacturing product was 17 percent of GDP. Since the only input considered is hours worked, these estimates are often described as *labor productivity*. Most of the data on employee-hours comes from the BLS's establishment survey, although for some workers other sources are used.

The BLS publishes a second category of estimates annually, using a more comprehensive definition of inputs into the production process; the result is referred to as *multifactor, or total-factor, productivity* and is represented by the term  $A$  in equation (1). The statistic is estimated by dividing product of a broad sector by an input index that is a weighted average of two indexes, one of labor inputs and the other of capital inputs. The index of labor inputs can be thought of as a quality-adjusted labor index; for broad sectors it is calculated as a weighted average of employee-hours for several groups of workers. The groups are defined by sex, level of education, and amount of experience. The capital input index is a weighted average of capital services from many different categories of structures, equipment, inventories, and land.

In both the quarterly and annual estimates, productivity in the narrow manufacturing sector is calculated using input and output measures that differ from the measures used to estimate productivity in the broader sectors. Manufacturing productivity is therefore not strictly comparable to the broad-sector estimates. For multifactor productivity, manufacturing labor input does not receive the demographic adjustments that the labor input receives for broader sectors. In addition to labor and capital, manufacturing's aggregate input index includes purchases of energy, other raw materials, and business services. Those additional items are crucial, since purchased inputs account for the bulk of manufacturing costs. With regard to output, the manufacturing measure is gross output, excluding shipments within the manufacturing sector. In contrast, for the broader sectors, output represents value added; accordingly, the value of material inputs is subtracted from gross output.

The BLS publishes a third category of estimates for particular industries. In this category, they estimate labor productivity for 150 specific industries, again using a different methodology from the other two categories. Multifactor productivity is also calculated for a smaller number of industries. The BLS first estimated industry productivity in 1898 in response to congressional concerns over the employment effects of labor-saving technology. Today, the choice of which industries to cover depends on data availability and therefore is heavily tilted toward manufacturing. Nonetheless, the BLS estimates productivity for important industries outside manufacturing, including mining, communications, banking, trade, and transportation. In these industry estimates, output indexes measure gross output and are taken from census surveys. The labor input is measured by employee-hours, without demographic adjustments. For multifactor productivity calculations, capital services and intermediate purchases supplement the labor input.

In order to supplement the BLS productivity estimates, many analysts construct their own numbers. Since GDP and population estimates are available for relatively lengthy time spans for many countries, GDP divided by population is often used as a rough estimate of labor productivity. Either the numerator or the denominator of this output-per-person ratio can be refined. Most importantly, instead of population, one could use the labor force, employment, or employee-hours. Many analysts also construct their own estimates of multifactor productivity. The main requirement is to have a method to construct an input index; in equation (1), for example, the input index is  $K^\alpha L^{1-\alpha}$ . By constructing one's own multifactor productivity index, an analyst can include the most relevant factors of production. Thus one might distinguish between skilled and unskilled labor or between privately owned and government-owned physical capital. Finally, industry productivity estimates have often been constructed directly from the NIPA measures of output by sector, which by definition represent value added rather than gross output.

## 2. POTENTIAL PITFALLS AND MEASUREMENT ISSUES

Any meaningful interpretation of national productivity statistics must account for the following potential pitfalls.

(1) Current estimates of productivity understate both its level and rate of growth. That bias reflects a basic difficulty in estimating real output. Real GDP, for example, is estimated by taking spending for over 1,000 separate categories, adjusting each spending estimate for price change, and summing the resulting estimates of real expenditure. The weak link in this chain is the adjustment for price change. Current procedures systematically overstate changes in prices and thereby understate both levels and rates of change of real GDP and productivity.

How large is the bias? A large volume of research has produced credible estimates for a large fraction of GDP; biases for a few items are mentioned below.

(a) Consumer spending accounted for 68 percent of GDP in 1996. A panel of experts (Boskin 1996) estimated that the rate of increase in the Consumer Price Index (CPI) was overstated by 1.1 percent per year in the mid-1990s. A large part of that bias is due to two related factors: inadequately accounting for the benefits of new goods that are not included in the CPI and inadequately accounting for the changing quality of items included in the CPI. When statisticians prepare estimates of real GDP, most prices for consumer spending are taken from the CPI, so much of that bias is carried over into the deflator for consumer spending.<sup>1</sup> One category of spending that does not use a price from the CPI is financial services such as checking accounts. Nominal amounts here are deflated by a procedure that *assumes* zero productivity growth. In contrast, the BLS productivity estimate for the banking industry found that productivity grew at a 2.0 percent annual rate from 1979 to 1990.

(b) Spending for nonresidential structures accounted for 3 percent of GDP in 1996. In many cases no price index has been constructed for deflating spending on these items, so a proxy such as an input price index is used. One analyst (Pieper 1990) estimates that this procedure tends to overstate new construction prices by at least 0.5 percent per year. Robert Gordon (1996a) noted that the official productivity index for construction has either declined or grown slowly for decades. The measured productivity level in U.S. construction has thus fallen by an implausible two-thirds relative to the Canadian productivity level in construction.

(c) Spending for producers' durable equipment accounted for 7 percent of GDP in 1996. A major study of a wide variety of evidence led Gordon (1990) to conclude that the implicit price deflator for producer durables overstated inflation in this category by 2.9 percent. Again, the main problem is that many of the prices of individual items come from producer price indexes that make inadequate allowance for new goods that are excluded from the indexes and for changes in quality of goods included in the indexes. The size of the bias is now probably less than

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<sup>1</sup> The CPI in 1997 was based on the goods and services consumers bought during 1982, 1983, and 1984. The implicit price deflator for consumer spending in the NIPAs, however, is based on the recent pattern of goods and services purchased, and that pattern changes each year. This difference in 1997 caused the CPI to overstate inflation by a greater amount than did the GDP price index for consumer spending. In 1998, the CPI will use an updated bundle of goods and services that, for a time, should narrow the difference between rates of change of the two indexes.

Gordon found, however, due to important methodological changes by the statistical agencies.

(d) A large part of government services consists of employee compensation, which accounted for 10 percent of GDP in 1996. Construction of real output in this category again *assumes* zero productivity growth. In contrast, productivity in a large number of federal civilian programs is estimated to have grown at a 1.5 percent annual rate (Kendrick 1991).

In short, current estimates of the level and growth rate of real GDP are biased downward by a substantial amount, and therefore estimates of productivity that are based on GDP are similarly biased, including all the BLS measures. These problems are not unique to the United States but are inherent in every country's statistical program. The major difficulty is that taking estimates of current dollar spending and disentangling real output and prices is difficult in an economy with rapid innovation. Nonetheless, research within statistical agencies and by academic economists has identified promising approaches for addressing some of the problems. An outstanding example is the research that led to quantifying the changing quality of computers in the United States. This change, implemented in the mid-1980s, had such large consequences that it led to the introduction of a new statistical formula, chain weighting, into the NIPAs in the 1990s. Both changes have substantially improved our understanding of the behavior of economic activity over the last few decades. What is lacking is the funding needed for additional basic research, for applied research on the practical methods needed to implement potential improvements for routine production of statistics, and for additional surveys to gather more raw data. Improving the quality of any product can be costly, and economic statistics are no exception.

(2) Growth rates of productivity are highly variable when measured over short periods of time. Moreover, rates measured over lengthy periods move predictably with the business cycle. Consequently, high rates of productivity growth usually accompany high rates of output growth, often near the beginning of cyclical expansions. Unfortunately, pundits may seize on a short period of rapid growth in output and productivity and proclaim that the trend rate of productivity growth has risen; later in the cycle it will become obvious that productivity is still near its old trend. When questioning whether the trend has shifted, it is best to look at a complete business cycle or longer. In the current cycle one might compare the latest productivity data with data from 1990, the year in which the peak of the last business cycle occurred, or 1989, the year in which some measures of the level of productivity peaked.

(3) Extra caution is required when using productivity estimates for individual segments of the economy. Partitioning the economy introduces an additional source of error into output and productivity statistics due to the difficulty of distributing inputs and outputs across sectors in a meaningful way. For example,

in the BLS industry studies of labor productivity, output is measured as gross value and thus inputs from other sectors are excluded. Therefore, increased outsourcing of services in a particular manufacturing industry would appear as higher measured productivity in that industry even if overall labor productivity did not change for all firms combined. But even when outsourcing is taken into account, as in the BLS multifactor productivity measures for manufacturing, a more subtle difficulty emerges. Suppose prices and quantities were measured accurately for manufacturing but that unmeasured quality improvements led to overestimates of price increases for business services. The real quantity of services used by the manufacturing sector would then be understated, and manufacturing productivity would be overstated.

### 3. HOW HAS PRODUCTIVITY BEHAVED OVER TIME?

Many economic historians believe that sustained productivity growth is a relatively recent phenomenon.<sup>2</sup> Further, if one concentrates on the relatively recent period in which sustained productivity growth has been evident in many nations, one can see a distinct tendency for the world's productivity to accelerate over time. This tendency is illustrated in Table 1 with data on per capita real GDP for several countries from 1820 to 1989. Before discussing the data, note that productivity statistics are currently not estimated as accurately as we would like. Moreover, as one moves back in time, the quality of the estimates deteriorates. A historian estimating GDP for an economy in the nineteenth century has only a small fraction of the data that is currently available to national product statisticians. Also, the quality of data can vary across countries. One particular problem is with countries that have large sectors where market forces of supply and demand are suppressed; for those countries, the market value of real output of the nonmarket sector is difficult to estimate.

Even with these qualifications, the data can be useful. In particular, one can note the extent to which productivity growth has risen. Consider first the countries leading in productivity. For most of the nineteenth century the United Kingdom had the highest level of productivity in the world, with a productivity growth rate of 1.2 percent from 1820 to 1890. In the twentieth century the United States has had the highest level of productivity, with a growth rate of 2.0 percent from 1913 to 1989. Next, consider two "growth miracles."<sup>3</sup> From 1950 to 1973, Japan's productivity level increased by a factor of almost 6, which resulted in an 8.0 percent annual rate of productivity growth. Over a longer

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<sup>2</sup> Jones (1988), for example, distinguishes between the last 1,000 years and the rest of mankind's existence.

<sup>3</sup> These are not the only examples that could have been mentioned; other countries have had similar periods of rapid growth as well.

**Table 1 Real Output per Capita**

	1820	1870	1890	1913	1950	1973	1989
United States	1,219	2,244 [1.2]	3,101 1.6	4,846 2.0	8,605 1.6	14,093 2.2	18,282 1.6]
United Kingdom	1,450	2,693 [1.2]	3,383 1.1	4,152 0.9	5,651 0.8	10,079 2.5	13,519 1.9]
Germany	902	1,251 [0.7]	1,660 1.4	2,506 1.8	3,295 0.7	10,124 5.0	13,752 1.9]
Japan	609	640 [0.1]	842 1.4	1,153 1.4	1,620 0.9	9,524 8.0	15,336 3.0]
Taiwan			564	608 [0.3]	706 0.4	2,803 6.2	7,252 6.1]
China	497	497 [0]	526 0.3	557 0.2	454 −0.5	1,039 3.7	2,538 5.7]
India	490	490 [0]	521 0.3	559 0.3	502 −0.3	719 1.6	1,093 2.7]
Latin America <sup>a</sup>	570	785 [0.3]	998 1.2	1,350 1.3	2,180 1.4	3,661 2.5	4,033 0.6]
Africa <sup>b</sup>	400	400 [0]	400 0	580 1.6	1,044 1.2	1,656 1.9	1,660 −0.3]

[Entries in brackets represent average annual rates of change from the preceding entry.]

<sup>a</sup>Average for Argentina, Brazil, Chile, Colombia, Mexico, and Peru.

<sup>b</sup>Average for Cote'd Ivoire, Ghana, Kenya, Morocco, Nigeria, South Africa, and Tanzania.

Notes: The figures in this table are from Maddison (1994), Table 2.1. Entries are per capita GDP, stated as dollar amounts at 1985 U.S. relative prices. Entries for Africa from 1820 through 1913 are described by Maddison as rough guesses.

period, 1950–89, Taiwan boosted productivity by a factor of 10, which led to a 6.2 percent annual rate of productivity growth. Such rapid rates of growth are simply not evident in pre–World War II data. Also, note productivity growth in the world's two most populous nations. Productivity stagnated in China and India for over a century but is now growing. All in all, productivity growth for countries containing much of the world's population, at varying stages of industrialization, has become distinctly faster. That trend, however, is not universal, with Africa being an important exception.

Two periods of productivity growth in the United States are now considered. Figure 1 illustrates per capita real GDP since 1869. Despite large departures during the Great Depression and World War II, this estimate of

productivity remains remarkably close to a trend of 2.0 percent annual growth.<sup>4</sup> That estimate, however, uses population as a loose proxy for labor input. Another view looks at post–World War II data that incorporate a more explicit measure of labor input, employee-hours. For more than two decades, the trend rate of productivity growth has been substantially lower than it was early in the postwar period. For example, multifactor productivity for nonfarm business, seen in Figure 2, rose at a 1.9 percent annual rate from 1948 to 1973 but only rose at a 0.1 percent rate from 1973 to 1994. Similar declines are evident in most other measures of productivity. As shown in Table 1, per capita output growth simultaneously declined in other mature industrial economies. Moreover, data for the current business cycle reveal no sustained pickup in the rate of productivity growth. For example, hourly output of nonfarm business grew at a 1.1 percent rate, both from 1973 to 1989 and from 1989 to 1997.

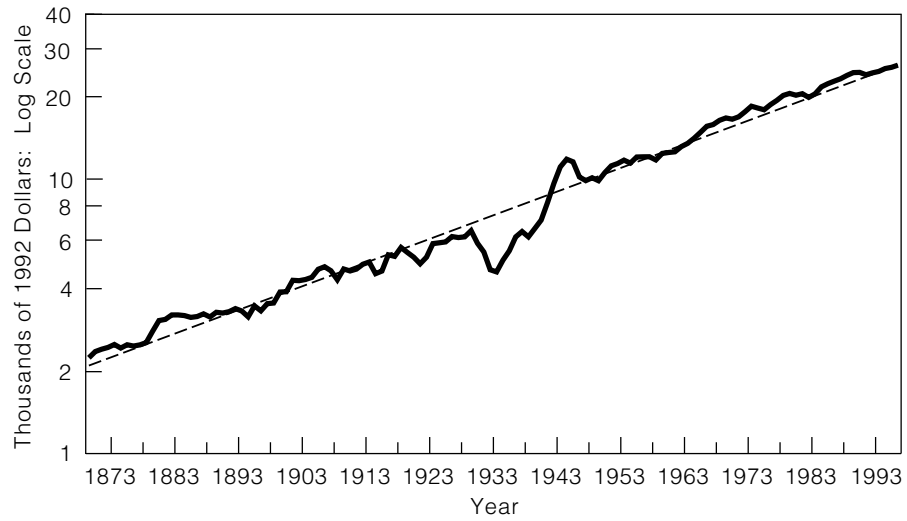
Since productivity growth leads to higher material standards of living, its apparent slowing has become the focal point of a large volume of analysis. There are several possible explanations, but before considering them, it may be helpful to consider the ultimate sources of productivity growth. If one looks at simple labor productivity, then physical capital accumulation and improved education appear to account for a substantial portion of measured productivity growth. The accumulation of physical and human capital has been extensively studied and quantified, and its contribution to the growth of labor productivity is not controversial. Additional sources of productivity growth include scientific and engineering advances, the realization of economies of scale, improvements in the management of organizations, and the shift in employment from low- to high-productivity sectors of the economy; these have been less well quantified, but the importance of each is also not controversial. Finally, a broad array of conditions apply to nations as a whole and can affect productivity growth. These include the effectiveness of the rule of law in predictably protecting property rights, the level and predictability of tax rates, the incentive effects of particular taxes and subsidies, the extent and methods of government regulation of business practices, the ability of a nation's system of financial institutions to channel funds to productive investment opportunities, and the extent to which monetary policy achieves low, stable rates of inflation over time. The exact importance of each item in this latter set is open to considerable debate.

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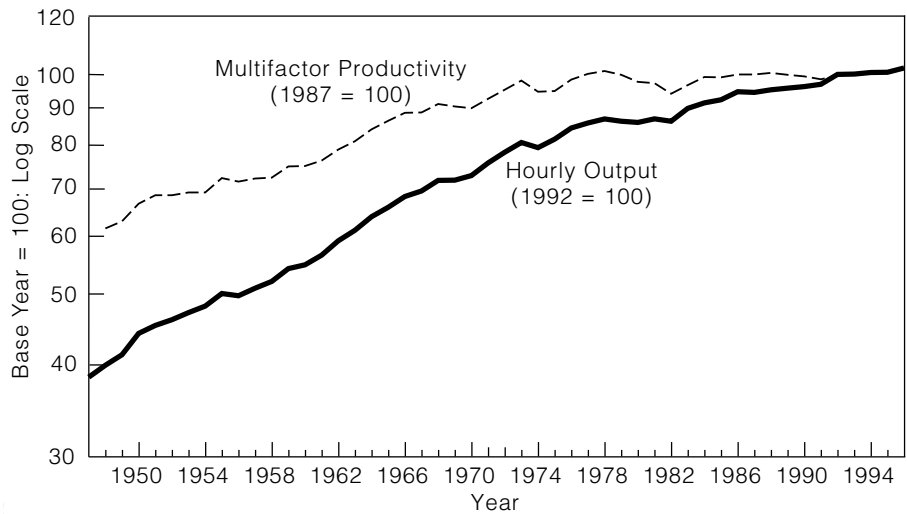
<sup>4</sup> The measure of GDP used in the figures in this article differs in an important respect from that used by Maddison (1994). Whereas Maddison's GDP data were constructed using a fixed base period, official data are now constructed using a chain-weighted index for real GDP. One effect of that difference is to slightly increase growth rates over long periods of time, such as in Figure 1.



**Figure 1 Real GDP Per Capita**



**Figure 2 Nonfarm Business Sector: Hourly Output and Multifactor Productivity**

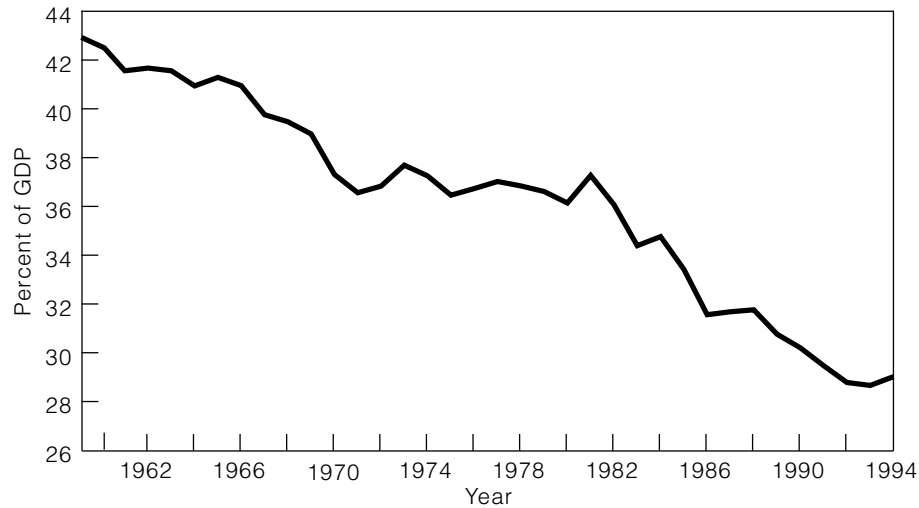


#### 4. DOES MISMEASUREMENT EXPLAIN RECENT PRODUCTIVITY BEHAVIOR?

Why did the trend rate of productivity growth in the United States and in other mature industrial economies slow in the early 1970s? Because it is difficult to measure productivity accurately, it is tempting to blame measurement problems (see, for example, Nakamura [1997]). In order for measurement problems to be convicted of that crime, however, analysts must dispel several reasonable doubts. Exactly what measurement problem suddenly worsened in the late 1960s or the early 1970s? And why did it affect all mature industrial economies simultaneously? The data in Table 1, for example, indicate that growth of per capita output declined in the United States, the United Kingdom, Germany, and Japan. Other productivity measures show an even more dramatic slowing. Until such questions can be answered, many observers will regard as unproven the hypothesis that an accurate estimate of productivity growth did not slow, even though measured productivity growth did. This conclusion also applies to a variant of the mismeasurement view, namely that while true productivity growth did slow in the 1970s and 1980s, it has rebounded in the 1990s, although that rebound is not being properly measured.

Zvi Griliches (1994) presented some evidence on the plausibility of the mismeasurement view. He classified output into sectors that were relatively “measurable,” such as manufacturing, and “unmeasurable,” such as finance. He then noted that the fraction of output in measurable sectors had declined over time. Figure 3 uses his classification to illustrate how the fraction of output from well-measured sectors has declined from 43 percent in 1959 to 30 percent in 1994. From one perspective, output *has* been getting more difficult to measure, since the poorly measured fraction has increased by 13 percentage points. But from another perspective, output has *always* been difficult to measure, since even in 1959 well-measured output was less than half of total output. For a quantitative assessment of the two views, consider the following numerical example. Suppose that productivity actually grew at a 5 percent annual rate in both the measurable and unmeasurable sectors but that it was incorrectly estimated as zero in the unmeasurable sector. Overall productivity growth would then have been estimated at 2.15 percent in 1959 and 1.50 percent in 1994. Thus even these large numerical values that almost certainly overstate the case would explain only part of the productivity slowdown.

Slifman and Corrado (1996) examined the measurement problem in a different manner. They found that labor productivity in nonfarm business had the expected slowing: it grew by 2.8 percent from 1960 to 1973 but only 1.1 percent from 1973 to 1996. But in the nonfarm corporate sector (which accounts for slightly over three-fourths of nonfarm business) productivity growth changed little, rising at a 1.8 percent rate from 1960 to 1973 and a 1.6 percent rate from 1973 to 1996. The difference in aggregate productivity behavior reflects the

**Figure 3 “Well-Measured” Output**

Note: Gross domestic product for the (1) Agriculture, Forestry, and Fishing, (2) Mining, (3) Manufacturing, (4) Transportation, (5) Communications, and (6) Electric, Gas, and Sanitary Services industries as a percentage of total gross domestic product.

nonfarm noncorporate sector, composed of proprietorships and partnerships, in which measured labor productivity rose at a 4.8 percent rate in the earlier period but fell at a 0.9 percent rate in the later period. Moreover, the profitability of that sector did not deteriorate even as productivity fell. Thus it appears that this relatively small part of the economy plays a disproportionately large role in overall productivity developments and lends credence to the mismeasurement view. At the same time, it is hard to imagine what form of mismeasurement accounts for the dramatic change. Also, the data that Slifman and Corrado presented do not rule out the possibility that the high growth of noncorporate productivity before 1973 was an aberration.

A final possibility of increased mismeasurement around 1973 is raised by the increased efforts to limit emissions of pollutants. The labor and capital used to reduce pollution is included in national economic statistics, but benefits like cleaner air and water are omitted. As a result, increased pollution-control efforts will reduce measured output and therefore measured productivity. While this argument is unassailable in principle, one may question its quantitative impact. For example, pollution abatement and control expenditure has typically been less than 2 percent of GDP. Also, the largest investments have been made by firms in measurable industries, mostly where the productivity slowdown has been less pronounced (the electric utility industry is a notable exception).

## 5. OTHER EXPLANATIONS OF SLOWER PRODUCTIVITY GROWTH

If mismeasurement is not the whole story, then what explains slower productivity growth? Several possible explanations are presented in this section.

### Energy Prices

A large increase in the price of energy was initially a prime suspect. In the 1970s, for example, many authors, such as John Tatom (1979), attributed much of the productivity slowdown to oil-price increases. The appeal of that hypothesis was in part due to the correspondence of two events: first, energy prices rose rapidly in 1973–74, and second, the year 1973 is often taken to be the dividing point between high- and low-productivity growth periods.<sup>5</sup> Interest in that explanation waned following the failure of productivity to accelerate after oil prices declined in the 1980s.

### Institutional Sclerosis

Mancur Olson (1988), however, presented a view that could give some importance to energy-price shocks despite the events of the 1980s. He proposed that major shocks, such as oil-price increases, can interact with rigidities in political systems to magnify the impact of shocks and also can cause the effects of shocks to persist for long periods of time. The simple story is that a shock that disturbs the status quo can lead political interest groups to spend resources to influence the distribution of output rather than use those resources to produce output. To the extent that country's political system is dominated by coalitions engaged in such behavior, the country is said to exhibit institutional sclerosis. In essence, Olson explains the productivity slowdown by a combination of initial shocks, including oil-price increases in the 1970s, magnified and propagated by sclerotic political systems in large, industrial economies including the United States.

Two papers provide some support for portions of Olson's view. Lars Ljungqvist and Thomas Sargent (1996) present a theoretical analysis, along with numerical calibration, of features of a prototypical European welfare state. They found that the labor market's adjustment to external shocks can be extremely lengthy and that indirect effects of a shock can be substantial; both are part of Olson's story. Also, Richard Vedder (1996) found a negative correlation between labor productivity growth and spending by the U.S. government for economic regulation. One would expect to see a negative correlation if regulations were introduced primarily to affect the distribution of income. The

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<sup>5</sup> Although it is conventional to take 1973 as the watershed year, by the late 1960s some analysts were discussing a slowing of productivity growth that had become evident.

argument would be stronger, however, if accompanied by an effort to assess the benefits of the regulations for which costs were extensively tallied.

In Olson's view, effects of positive shocks are also magnified and propagated through time. For example, a positive shock to a sclerotic economy could initially be amplified due to a rising fraction of new, successful ventures. The positive effects, including higher growth and a lower price level, would then persist as the degree of sclerosis in the economy declined. That decline would be a consequence of individuals finding it more profitable to engage in productive activity than in seeking to influence the political process.

### **Technical Change and Learning**

One of the striking features of the post-1973 period has been the falling cost of computing and the resulting widespread use of computer power. From 1973 to 1996, real gross investment in computers and peripheral equipment increased by a factor of 892 as the price of computing power fell by a factor of 44. The coincidence of this technological explosion and falling productivity growth has puzzled many observers. In an attempt to reconcile the two, Andreas Hornstein and Per Krusell (1996) note that people may need substantial amounts of learning in order to use computers effectively. After modifying a standard model to require that learning accompany a technological change, they find that a technological change can boost output growth in the long run, even though it causes an initial period of lower productivity. In addition, they argue that the use of computers may be especially efficient at increasing the quality of goods produced. Given the difficulties of accounting for quality improvement in economic statistics, they conclude that growing computer use may worsen the measurement problem and obscure any rebound in productivity. Griliches (1994) emphasizes that point by noting that the unmeasurable sector accounts for fully three-quarters of new computer investment. Also, Baily and Gordon (1988) present evidence on substantial investments in computing that produce unmeasured convenience to consumers in several specific areas.

A complementary theme, proposed by Paul David (1990), identifies parallels between the recent adoption of the computer and the adoption of electric power a century ago. In each case the technology improved rapidly over a fairly long time, and the technology gradually moved into widespread use. Even more intriguing was the pronounced slowing in aggregate productivity growth during 1890-1913, when the world's two leading economies, the United States and Britain, rapidly increased their use of electricity. David attributed much of the delay between the introduction of electricity and improved productivity to a lag in designing manufacturing facilities that made optimal use of electric motors and later a lengthy delay before it became profitable to replace older facilities. He also noted that electrification led to higher-quality products that would be mismeasured in economic statistics; for example, electric light greatly improved

the quality of illumination, but that effect is ignored in conventional statistics.<sup>6</sup> In short, here is a historical example of a revolutionary new technology that significantly raised output in the long run, although the introduction may have temporarily depressed measured productivity.

### **Research and Development**

To better understand the role of technology on output growth, analysts have long studied national spending on research and development (R&D) as a proxy for general scientific and engineering advances. Gordon Richards (1997) has incorporated data on R&D spending into a statistical model designed to study long-run growth. In many ways the model is standard, although it differs from most by allowing for small increasing returns to scale for all factors of production taken together. More significantly, he departs from the norm by distinguishing computers from other physical capital stocks and making the efficiency of R&D a function of computer quality, which in his model depends inversely on the price of computers. One conclusion from his analysis is that R&D added 1.2 percent to annual labor productivity growth in the 1960s, but only 0.5 percent from 1973 to 1990, thereby explaining a substantial portion of the productivity slowdown. Moreover, he found that labor productivity growth increased in the 1990s, and he projects that increase to continue, with labor productivity growth peaking at 1.8 percent around 2010 (versus 1.1 percent in the early 1990s).

### **An Optimistic Summary**

The bits of evidence presented above can be combined into a consistent optimistic scenario. The productivity slowdown was a real phenomenon, although its severity is overstated by biased economic statistics. The relative growth of the unmeasurable sector is partly responsible for the overstatement. Furthermore, it is plausible that computers—especially in the unmeasurable sector—have boosted quality in ways that confound traditional measurement. For one example, computers have allowed development of several new diagnostic techniques that have made medical treatment much more effective, including computerized tomography (CT) scanners. Trajtenberg (1990) has shown that while the price of a CT scanner, which would be included in a producer price index or a GDP price index, increased by a factor of 2.5, its quality-adjusted price index

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<sup>6</sup> William Nordhaus (1997) provides fascinating details on the provision of lighting throughout history. Most relevant to David's (1990) hypothesis, Nordhaus focuses on the cost of providing what consumers want, namely a given amount of illumination, and contrasts that with the traditional price-index practice of valuing items like lamps and fuel. The difference between the two approaches is striking. Whereas the traditional index increased by a factor of three from 1800 to 1992, the true index fell by a factor of 1,000! He further estimates that real output growth has been underestimated by 0.036 percent per year due to bias in price indexes for lighting alone.

fell by a factor of more than 1,400.<sup>7</sup> In short, the growing use of computers, especially in industries for which output is most difficult to measure, explains why the mismeasurement of productivity could have increased around the time of the reported slowdown of productivity growth.

Analysts who subscribe to this view expect productivity growth to be higher in the immediate future. First, part of the measured decline was simply measurement error. Second, the Hornstein-Krusell-David argument would suggest that although growth has been temporarily depressed, it is nonetheless set to rebound. A similar prediction comes from Richards's (1997) statistical analysis, based on different data. And Olson (1988) provides a rationale for even temporary positive developments to have counterintuitively large and long-lasting effects.

Since a key part of the optimistic scenario is a high rate of return to R&D, it may be helpful to consider why many economists might find that assumption plausible. The U.S. economy has become increasingly open to international trade and investment over the last half century because of lower tariffs, quotas, and other legal barriers to trade. Also important have been large declines in unit costs of transportation and communication and a shift in the composition of items traded from bulk commodities, such as steel, to services and physically smaller items, such as semiconductors. Why does openness matter? Many would argue that the U.S. economy has a comparative advantage in generating new ideas and incorporating them into tradeable products. Expanded trade therefore would be expected to raise demands for new research, for educated workers to apply that research, and for computer usage. A higher demand for new research would lead to a higher rate of return on new research. And as workers shifted into highly valued research-intensive activities, productivity would rise.

### **A Less-Optimistic Scenario**

Not all analysts subscribe to the optimistic scenario presented above. For example, Robert Gordon (1996b) has argued that total-factor productivity growth in the United States increased at an annual rate of 0.5 percent or less in much of the nineteenth and early twentieth centuries and at an annual rate of 1.5 percent from 1915 to 1965. Since 1965 it has reverted back to growth at an annual rate of 0.5 percent or less. To him, the rapid growth from 1915 to 1965 is unusual. He believes it is due to a few major technological developments, including the electric motor, the internal combustion engine, communication technology, and mass entertainment, which includes radio, movies, and television. In his view, the computer has not had as much of an impact as these earlier developments.

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<sup>7</sup> Of course, as the better scanner lowers the cost or improves the quality of medical care, consumer welfare increases and a cost-of-living index for consumers would fall.

He therefore believes that at least 1 percentage point of the productivity slowdown is real and should not be expected to improve. To support his position, he suggests the thought experiment of comparing the rise in the standard of living of the average American between 1915 and 1955 with the rise between 1955 and 1995. He finds the former to be a period of substantial improvement, with an average person's daily life literally transformed, but the latter period to have comparatively little fundamental change.

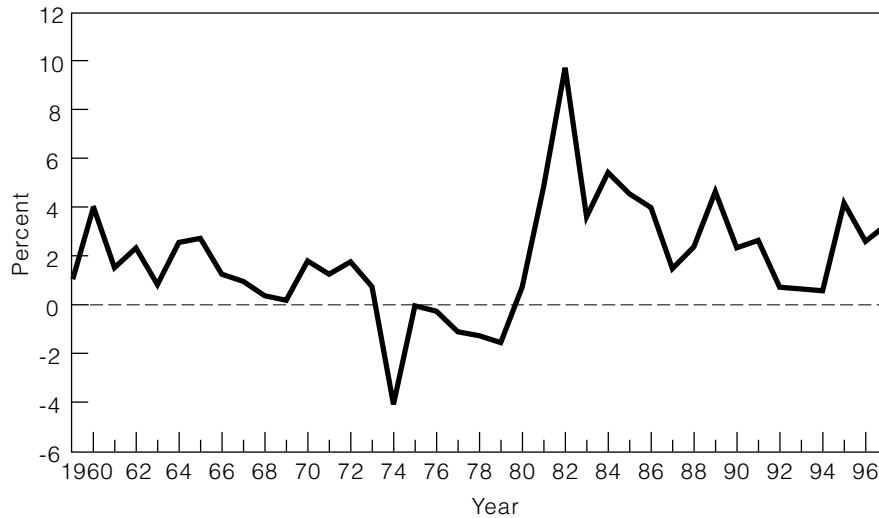
An important part of Gordon's (1996b) argument involves a small contribution of computers to productivity growth. Supporting evidence comes from Daniel E. Sichel (1997), who examined the impact of computers on growth and found little evidence of a substantial impact. He noted that computer hardware represents only a small part of the nation's capital stock; that conclusion does not change even if software is correctly measured and added to the analysis. Also, he argued that improvements in office automation and information processing equipment did not begin with the computer but have been occurring for over a century. A wide variety of equipment was adopted, including punched-card tabulators, mechanical calculators, and electric typewriters. He therefore sees the growing use of computers as a continuation of a trend rather than a discrete technological shift. In addition, Sichel made the case that mismeasured output growth does not account for his results.

Charles Jones (1997) took a different approach. He identified two important factors, other than capital accumulation and technology, that have had major impacts on U.S. economic growth. First, median years of schooling for adults rose from 9.3 years in 1950 to 12.0 years in 1967 and then to 12.8 years in 1993. Second, the fraction of the labor force consisting of scientists and engineers engaged in R&D rose from 0.26 percent in 1950 to 0.72 percent in 1967; after a subsequent fall it has risen to 0.78 percent in 1993. For both, the substantial slowing of improvement after 1967 is striking. Jones's analysis uses a fairly conventional statistical model that incorporates increasing levels of both education and research and allows for modestly increasing returns to scale. In that model, increases in education or research can boost the steady-state level of output or productivity, but once the steady state is achieved, there is no effect on growth rates. He observes that both the amount of schooling per person and the nation's research effort must eventually stabilize, and he concludes that as they stabilize in the future, output growth will slow. Accordingly, he calculates that productivity growth will also slow to an annual rate of 0.6 percent.

## **6. RESOLVING THE DIFFERENT VIEWS**

The controversy over slowing productivity growth may remind the reader of the old line that if all the economists in the world were laid end to end, they wouldn't reach a conclusion. In this case, the importance of the problem has led



**Figure 4 Realized Real Interest Rates**

economists to explore possible explanations, but the lack of definitive data has prevented a consensus from emerging. More research would clearly be helpful. In particular, it would at least be useful to have bounds on the probable amount of bias in price, output, and productivity statistics for several benchmark years. With such bounds in hand, one could look at interrelations among macroeconomic statistics for indirect evidence on whether either the optimistic or the pessimistic scenarios could be ruled out.

To illustrate the value of such bounds, consider the behavior of real interest rates. Figure 4 shows the movements over time of one measure of ex post real rates, the one-year Treasury rate for each January minus the next 12-month percentage change in the consumer price index, excluding volatile food and energy prices (core CPI). Economic theory states that real rates should move with productivity growth; thus, for example, if the trend rate of productivity growth were to increase, that would tend to raise real interest rates.<sup>8</sup> Now suppose that we knew that there was no ongoing change in the amount of bias

<sup>8</sup> Of course, other factors also affect interest rates. In the figure, at least part of the downturn in the 1960s and 1970s reflected the slow adjustment of expectations and institutions to an inflationary monetary policy, and the upward spike in 1982 represents the shift to a disinflationary monetary policy. One also could adjust for other items that could have affected interest rates, such as the business cycle or fiscal policy.

in the core CPI.<sup>9</sup> One could then look for a trend in real rates. The absence of a downward trend would contradict the pessimistic story.

One could look at other relationships as well, such as real wages tracking the trend in productivity growth. The point is to have some bounds on movements of measurement biases over time; naturally, the tighter the bounds, the sharper the inferences that can be made. Also, the normal course of research will reveal which of the empirical studies mentioned above can withstand tests of replication by different authors and checks for robustness of the results to minor specification changes. And normal research will either tighten the theoretical work that is loosely specified or point out any internal inconsistencies discovered. Then we will better understand the productivity experience of the last half century.

## 7. FOR ADDITIONAL INFORMATION

The *Monthly Labor Review*, published by the BLS, often contains articles on the behavior of productivity and the preparation of productivity statistics. In addition, it contains tables that display recent data from each of the productivity programs.

The BLS also periodically publishes the *BLS Handbook of Methods*. This is an invaluable document for anyone wanting an in-depth explanation of the procedures used by the BLS to calculate economic statistics. Chapters 10 and 11 deal with productivity and were important sources for the preparation of this article.

The BLS makes a large volume of historical data and news releases available on the Internet (<http://www.bls.gov>). Some of its publications are also available at its web site, including the *Handbook of Methods*.

Since the output portion of productivity statistics comes from the National Income and Product Accounts, readers may find it helpful to consult the *Survey of Current Business* for articles about the preparation of GDP and related statistics. A convenient source of methodological articles from that publication is the web site of the Bureau of Economic Analysis (<http://www.bea.doc.gov>).

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<sup>9</sup> If the bias in measuring the CPI were increasing, that would bias estimates of real interest rates downward.

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