

# **Technology and Economic Performance in the American Economy**

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I am grateful to Richard Nelson, Benn Steil, and David Victor for helpful comments and to Stuart Gurrea for preparing the figures.

# **"Technology and Economic Performance in the American Economy"**

## **ABSTRACT**

This paper examines the sources of the U. S. macroeconomic miracle of 1995-2000 and attempts to distinguish among permanent sources of American leadership in high-technology industries, as contrasted with the particular post-1995 episode of technological acceleration, and with other independent sources of the economic miracle unrelated to technology. The core of the American achievement was the maintenance of low inflation in the presence of a decline in the unemployment rate to the lowest level reached in three decades. The post-1995 technological acceleration, particularly in information technology (IT) and accompanying revival of productivity growth, directly contributed both to faster output growth and to holding down the inflation rate, but inflation was also held down by a substantial decline in real non-oil import prices, by low energy prices through early 1999, and by a temporary cessation in 1996-98 of inflation in real medical care prices. In turn low inflation allowed the Fed to maintain an easy monetary policy that fueled rapid growth in real demand, profits, and stock prices, which fed back into growth of consumption in excess of growth in income.

The technological acceleration was made possible in part by permanent sources of American advantage over Europe and Japan, most notably the mixed system of government- and privately-funded research universities, the large role of U. S. government agencies providing research funding based on peer review, the strong tradition of patent and securities regulation, the leading worldwide position of U. S. business schools and U. S.-owned investment banking, accounting, and management-consulting firms, and the particular importance of the capital market for high-tech financing led by a uniquely dynamic venture capital industry. While these advantages help to explain why the IT boom happened in the United States, they did not prevent the U. S. from experiencing a dismal period of slow productivity growth between 1972 and 1995 nor from falling behind in numerous industries outside the IT sector.

The 1995-2000 productivity growth revival was fragile, both because a portion rested on unsustainably rapid output growth in 1999-2000, and because much of the rest was the result of a doubling in the growth rate of computer investment after 1995 that could not continue forever. The web could only be invented once, Y2K artificially compressed the computer replacement cycle, and some IT purchases were made by dot-coms that by early 2001 were bankrupt. As an invention, the web provided abundant consumer surplus but no recipe for most dot-coms to make a profit from providing free services. High-tech also included a boom in biotech and medical technology, which also provided consumer surplus without necessarily creating higher productivity, at least within the feasible scope of output measurement.

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## Introduction

The miracle of U. S. economic performance between 1995 and mid-2000 was a source of pride at home, of envy abroad, and of puzzlement among economists and policymakers.<sup>1</sup> The Federal Reserve presided over quarter after quarter of output growth so rapid as to break any speed limit previously believed to be feasible. As the unemployment rate inched ever lower, reaching 3.9 percent in several months between April and October, 2000, the Fed reacted with a degree of neglect so benign that late in the year 2000 short-term interest rates were barely higher than they had been five years earlier and long-term interest rates were considerably lower.<sup>2</sup>

The miracle began to unravel in the U. S. stock market, when the tech-influenced NASDAQ stock market index fell by half between March and December, 2000. Soon the unraveling reached the real economy, with a steady decline in the *growth rate* of computer investment after the beginning of 2000 and a decline in the *level* of industrial production after September. As this paper went to press, it was not yet clear whether the evident slowdown in U. S. economic activity in 2000-2001 would be of short or long duration, and to what extent the pillars of the 1995-2000 miracle would crumble or just shed a bit of dust.

Whatever the ultimate dimensions of the post-2000 economic slowdown and its aftermath, much of the 1995-2000 achievement was sure to remain, including

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1. Lawrence Summers spoke for many economists and policymakers recently when he characterized this widespread puzzlement as "paradigm uncertainty." See *Business Week*, "The Economy: A Higher Safe Speed Limit," April 10, 2000, p. 242.

2. The Treasury bill rate in September, 2000 at 6.00 percent was barely higher than the 5.64 percent registered in December, 1994, while the 30-year government bond rate over the same period fell from 7.87 percent to 5.83 percent.

the fruits of the post-1995 productivity growth revival, the investment goods and consumer durables that were produced during the investment boom, and acknowledged U. S. leadership in the information technology (IT) industries that had sparked the boom. This paper is primarily concerned with the conjunction of events that help us to understand the miracle, including those transitory components of the 1995-2000 economic environment which ultimately disappeared and help us understand why the period of rapid growth eventually came to an end.

The essence of the miracle was the conjunction of low unemployment and low inflation. Fed policy avoided any sharp upward spike in short-term interest rates such as had happened during the previous expansion in 1988-89 because of the perception that accelerating inflation was not a problem, despite a much lower unemployment rate than the minimum achieved in the earlier expansion.

Policy reactions were less aggressive in the late 1990s than in the late 1980s, because the economy appeared to have experienced a sharp change in behavior along at least two dimensions. Unemployment could be allowed to decline because inflation remained low. The second change of behavior was in the growth of productivity. After resigned acceptance of the so-called "productivity slowdown," more than two decades following 1973 when output per hour grew at barely one percent per annum (well under half of the rate experienced before 1973), analysts were astonished to observe productivity growth at a rate of nearly three percent as the average annual rate for 1996-2000 and an unbelievable 5.3 percent in the four quarters ending in mid-2000.<sup>3</sup>

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3. Part of this change in perception was an illusion based on a change in the measuring rod. The annual growth rate of output per hour for 1972-95 was 1.1 percent per year based on

Falling unemployment, low inflation, and accelerating productivity growth brought many other good things in their wake. In February, 2000, the American economy set a record for the longest business expansion since records began in 1850. Profits surged and, at least until early in the year 2000, stock market prices grew even faster than profits, showering households with unheard-of increases in wealth that in turned fueled a boom in consumption and an evaporation of household saving (at least as conventionally measured, excluding capital gains). The Federal government participated in the good times, enjoying a 64 percent increase in personal income tax revenues between 1994 and 1999, fueled by strong income growth and the capital gains resulting from a tripling of stock market prices over the same interval.<sup>4</sup> And the gains from the boom were not limited to the top 5 or 10 percent of the income distribution. For the first time since the early 1970s, gains in real income were enjoyed by households in the bottom half of the income distribution, and in April, 2000, the unemployment rates for blacks and Hispanics reached the lowest levels ever recorded.<sup>5</sup>

Perhaps the greatest contrast of all was between the glowing optimism in early 2000 that all was right with the American economy, especially in contrast to most of the other developed nations, whereas a decade earlier nothing seemed to be going right. In 1990 Japan had been king of the mountain, and the United

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data available prior to 1999 but jumped to 1.5 percent per year as a result of data revisions announced in late 1999.

4. The S&P 500 stock market index increased from an average of 455 in December, 1994, to 1505 in the week ending April 1, 2000 and was still above 1400 in early November, 2000.

5. Data on real family incomes show a pattern of equal growth rates by income quintile for 1947-79 but sharp divergence between decreases at the bottom and increases at the top during 1979-97. See Michel *et. al.* (1999), Figure 1E, p. 52.

States then appeared to be clearly inferior to Japan along almost every dimension, including inflation, unemployment, productivity growth, technical dynamism, and income inequality. The emerging economic slowdown in late 2000 and early 2001 suggested that the American switch from an inferiority to a superiority complex had been too abrupt, and that the miracle of the late 1990s had perhaps been less permanent and complete than economic pundits had proclaimed only a year earlier.

If there was a consensus about anything as the boom years of the miracle were followed by a slowdown and perhaps a subsequent recession, it was that the core of the miracle was an acceleration in technological progress centered around the "New Economy" of computers, IT more generally, and the internet, and that the clearest manifestation of the miracle in the economic data – the post-1995 productivity growth revival – could be traced directly to the IT revolution. One way of describing the changing relationship between technology and economic performance is through Robert M. Solow's famous 1987 saying that "we can see the computer age everywhere but in the productivity statistics." For a decade economists took "Solow's paradox" as a truism, noting the continuing co-existence of explosive growth in computer use and dismal growth in labor productivity, and they differed only in their explanations.<sup>6</sup> But by 1999-2000 a consensus emerged that the technological revolution represented by the New Economy was responsible directly or indirectly not just for the productivity growth acceleration,

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6. The explanations included "the computers are not everywhere," or "there must be something wrong with the productivity statistics," or "there must be something wrong with the computers." The best compendium and assessments of these and other alternative explanations is provided by Triplett (1999).

but also the other manifestations of the miracle, including the stock market and wealth boom and spreading of benefits to the lower half of the income distribution.

In short, Solow's paradox is now obsolete and its inventor has admitted as much.<sup>7</sup>

This paper explores the interrelations between the ebb and flow of U. S. economic performance and the role of technology. We quantify the role of technology in general and IT in particular in achieving the U. S. productivity acceleration of the late 1990s and provide an analysis that suggests that some of the acceleration may be temporary and may not persist. In determining the role of alternative sources of the technological acceleration and American domination of IT manufacturing and software production, we shall explore the role of mechanisms and incentives in the private sector, foreign competition, and government policy. The role in the U. S. success of its heterogeneous system of public and private universities, peer-reviewed government research grants, and strong tradition of patent and securities regulation are also emphasized. The paper concludes with observations on the role of immigration as a source of recent American success and an area where policy has an important role to play. Throughout the analysis, the American success story is qualified not just by the emergence of an economic downturn in 2000-2001, but also by the remaining less favorable elements of American exceptionalism when viewed from abroad, especially rising economic inequality that limited the spread of the "miracle" across the income distribution.

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7. Solow is quoted as such in Uchitelle (2000).

## **Dimensions of Macroeconomic Performance**

We begin by examining several indicators of economic performance and discuss several hypotheses that have been suggested to explain the multi-dimensional improvement of performance in the late 1990s.

### **Inflation and Unemployment**

Figure 1 plots the unemployment rate on the same scale as the inflation rate for the Personal Consumption deflator.<sup>8</sup> The unemployment rate in 1999-2000 fell to four percent, the lowest rate since the 1966-70 period during which inflation accelerated steadily. Yet in 1998 and early 1999, prior to the 1999-2000 upsurge in oil prices, inflation not only failed to accelerate but rather decelerated.

Taking a general view of the unemployment-inflation relationship, it appears superficially that the only support for a negative Phillips-curve unemployment-inflation tradeoff is based on the 1960s Vietnam-era experience, with a bit of further support from the economic expansion of 1987-90. In other periods, especially during 1972-85 and 1995-99, the unemployment and inflation rates appear to be positively correlated, with the unemployment rate behaving as a lagging indicator, moving a year or two later than inflation. While this appearance

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8. The deflator for Personal Consumption Expenditures, part of the National Income and Product Accounts, is preferable to the Consumer Price Index because it has been revised retrospectively to use a consistent set of measurement methods, whereas the CPI is never revised.

of a positive tradeoff led some economists, notably Robert E. Lucas, Jr. and Thomas Sargent back in the 1970s to declare the Phillips curve to be "lying in wreckage," at the same time a more general model of inflation determination was developed that combined an influence of demand (i.e., a negative short-run relation between inflation and unemployment), supply (in the form of "supply shocks" like changing real oil prices), slow inertial adjustment, and long-run independence of inflation and the unemployment rate.<sup>9</sup> During the 1980s and the first half of the 1990s this more general model was adopted as the mainstream approach to inflation determination by textbook authors and policymakers alike, but in the late 1990s it was challenged again by the simultaneous decline in unemployment and deceleration of inflation evident in Figure 1.

At the end of the decade no consensus had yet emerged to explain the positive correlation of inflation and unemployment in the late 1990s. I have attempted to use a common framework to explain why the performance of the 1970s was so bad and of the 1990s was so good, pointing to the role of adverse supply shocks in the earlier episode and beneficial supply shocks more recently.

In my interpretation (1998) inflation in 1997-98 was held down by two "old" supply shocks, falling real prices of imports and energy, and by two "new" supply

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9. The more general approach was developed in Gordon (1977, 1982). The evolution of this approach is described in Gordon (1997).

shocks, the accelerating decline in computer prices (see Figure 9 below) and a sharp decline in the prices of medical care services made possible by the managed care revolution. In retrospect my analysis, while still valid regarding the role of the supply shocks, did not place sufficient emphasis on the productivity growth revival as an independent source of low inflation. Between 1995 and late-2000 wage growth accelerated substantially from 2.1 to above 6 percent at an annual rate, thus appearing to validate the Phillips curve hypothesis of a negative tradeoff between unemployment and wage growth.<sup>10</sup> However, soaring productivity growth during the same period prevented faster wage growth from translating into growth in unit labor costs (defined as wage growth minus productivity growth). If productivity growth were to decelerate, then it added one more element to the list of transitory elements that had held down inflation in the late 1990s. Any of the items on the list – falling relative import and energy prices, a faster rate of decline in computer prices, moderate medical care inflation, and the productivity growth revival itself – could turn around and put upward rather than downward pressure on the inflation rate. This had already begun to happen as a result of higher energy prices, as the growth rate of the price index for personal consumption expenditures had already more than doubled from 1.1 percent in 1998 to 2.4

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10. These figures refer to the growth in nonfarm private compensation per hour.

percent in 2000.

Figure 2 compares (with annual rather than quarterly data) the actual unemployment rate with the natural unemployment rate (or NAIRU). The concept of the natural unemployment rate used here attempts to measure the unemployment rate consistent with a constant rate of inflation in the absence of the "old" supply shocks, changes in the relative prices of imports and energy.<sup>11</sup>

The acceleration of inflation during 1987-90 and the deceleration of inflation during 1991-95 are explained by movements of the actual unemployment rate below and then above the natural rate. It is the dip of the actual unemployment rate below the natural unemployment rate in 1997-2000 which raises questions about the behavior of inflation.<sup>12</sup> Perhaps the natural rate has declined more than is depicted here.<sup>13,14</sup>

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11. Allowance is also made for the role of the imposition and removal of the Nixon-era price controls during 1971-74.

12. In Figure 1 the decline of inflation in 1997-98 and its resurgence in 1999-2000 can be explained entirely by the "old" supply shocks, the behavior of the real prices of imports and energy.

13. Subsequent to my research on the NAIRU (Gordon, 1998), Eller (2000) has updated my research and made numerous improvements in my specification. However, Eller is unable to find any technique which yields a NAIRU below 5.0 percent in late 1999.

14. In addition to the role of computer prices and medical care prices in holding down inflation relative to that which would be predicted by the unemployment gap in Figure 2, several other changes in labor markets are considered by Katz and Krueger (1999). These include a declining share of youth in the working-age population, the imprisonment of some young adult males who would otherwise be unemployed, and the increased role in matching jobs and the unemployed played by temporary help agencies. I would add to this list the benefit of legal and illegal immigration in providing an additional supply of workers needed by tight labor markets (I return to this theme at the end of the paper).

## Monetary Policy, the "Twin Deficits," Saving, and Investment

The response of the Fed's monetary policy is summarized in Figure 3, which displays annual values of the Federal funds rate, which is controlled directly by the Fed, and the corporate bond rate. The Federal funds rate barely changed on an annual basis in the five years 1995-99 and during that period was much lower than reached in previous tight money episodes in 1969, 1974, 1981, and 1989, each of which can be interpreted as the Fed's response to an inflation acceleration that did not occur in 1995-99. Throughout the 1990s the corporate bond rate declined, reflecting both the behavior of short-term interest rates and also the perception that corporate bonds had become less risky as memories of the most recent 1990-91 recession receded into the past. The level of the corporate bond rate in 1999 was lower than in any year since 1969, helping to explain the longevity of the economic expansion and the ongoing boom in investment.

Until the late 1990s the U. S. economy appeared to be plagued by the "twin deficits," namely the government budget deficit and current account deficit.<sup>15</sup> In the casual discussion of causation that became typical during the 1980s and early 1990s, U. S. domestic saving was barely sufficient to finance domestic investment, requiring that any government deficit be financed by foreign borrowing. When both the government budget surplus and current account surplus are plotted as a share of GDP, as in Figure 4, we see that a tight relation between the "twin surpluses" or "twin deficits" is more the exception than the rule and occurred

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15. All references to the government budget deficit in this paper refer to the combined current surplus or deficit of all levels of government — federal, state, and local. See *Economic Report of the President*, January 2001, Table B-82, third column, p. 371.

most notably during the intervals 1960-70 and 1985-90.<sup>16</sup> In the 1990s the two deficits have moved in opposite directions to an unprecedented degree – the arithmetic difference between the government surplus and current account surplus changed from -4.2 percent of GDP in 1992 to +7.3 percent of GDP in 2000, a swing of 11.5 percent of GDP, or more than \$1 trillion.

This dramatic swing is easy to explain qualitatively if not quantitatively. A booming economy boosts the government budget surplus as revenue rises more rapidly than expenditures but also turns the current account toward deficit as imports grow more rapidly than exports. The magnitude of the current account deterioration seems roughly consistent with the excess of economic growth in the U. S. compared to its trading partners (the ability of which to purchase U. S. exports during 1998-99 was impaired by the financial crises in Asia, Brazil, and Russia, and continuing stagnation in Japan). But the magnitude of the government budget improvement appears to defie explanation, as each successive forecast by the Congressional Budget Office has become waste paper almost as fast as it has been published. Landmarks in the budget turnaround were the tax reform legislation of 1993 and 1996 and the huge surge of taxable capital gains generated by the stock market boom.

During the long period during which the government ran a budget deficit, a consensus emerged that the main harm done by the deficit was the erosion of "national saving," the sum of private saving and the government surplus.<sup>17</sup> Since

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16. The identity governing the relationship in Figure 4 is that the government budget surplus ( $T-G$ ) equals the current account surplus ( $X-M$ ) plus the difference between domestic private investment and domestic private saving ( $I-S$ ). During most of the period between 1974 and 1995, the government budget surplus was a larger negative number than the current account surplus, implying that investment was substantially less than saving. After 1996 this relationship reversed sharply.

17. Using the notation in the previous footnote, national saving equals total investment,

private investment could exceed national saving only through foreign borrowing, a low rate of national saving inevitably implied a squeeze on domestic investment, a reliance on foreign borrowing with its consequent future interest costs, or both. The only solution was to achieve some combination of a marked increase in the private saving rate or a turnaround in the government budget from deficit to surplus. Indeed, this pessimistic interpretation was validated in the numbers for a year as recent as 1993, when the net national saving rate reached a postwar low of 3.4 percent of GDP, down from a peak of 12.1 percent in 1965, and net domestic private investment was only 4.5 percent, down from 11.3 percent in 1965 (see Figure 5).

Those who had predicted that an ending of government deficits would stimulate private investment were vindicated, as the 1993-2000 increase in the investment ratio of 4.2 percentage points absorbed much of the increase in the government budget surplus over the same period of 7.1 points. The increase in national saving made possible by the budget turnaround was, however, almost entirely offset by a decline in the private saving ratio of 6.3 percent, requiring added borrowing from abroad (an increase in the current account deficit of 3.4 percent) to finance the extra investment.<sup>18</sup> Since these ratios are linked by definitional relationships, there is no sense in which these movements can be linked by attributions of cause and effect. It would be just as accurate to say that everything that changed after 1993 was an indirect effect of the New Economy and accompanying technological acceleration which (a) boosted the government budget

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domestic and foreign:  $S + T-G = I + X-M$ .

18. The data compare 1993 with 2000:Q3 and are taken from the *Economic Report of the President*, January 2001, Table B-32, pp. 312-13. Private saving is taken as the printed number plus the statistical discrepancy, and the government surplus is derived as a residual ( $T-G = I-S+NX$ ).

through income growth and capital gains, (b) created new incentives for private investment, (c) raised imports more than exports by boosting domestic income growth compared to foreign income growth, and (d) caused private saving to erode as stock market gains boosted the growth of domestic consumption beyond that of disposable income.

The final element in this chain of causation, the link between the stock market boom and the collapse of household saving, is illustrated separately in Figure 6. If we relate the S&P 500 stock market index to nominal GDP, this ratio more than doubled in the four short years between 1995 and 1999, after declining by two-thirds between 1965 and 1982. The negative correlation between the stock market ratio and the household saving rate is evident in the data and is just what would be expected as a result of the "wealth effect" embedded in Modigliani's original 1953 life-cycle hypothesis of consumption behavior. Putting Figures 5 and 6 together, we see that in the late 1990s rapid economic growth was fueled both by an investment boom financed by foreign borrowing and by a consumption binge financed by capital gains. Both of the latter were related, because the current account deficit was financed by willing foreigners eager to benefit from profits and capital gains in the buoyant American economy; a reversal of the stock market could cause all of this to unravel, including an end to the excess of growth in consumption relative to growth in disposal income, as well as a withdrawal of foreign funds that would push down the U. S. dollar. While some worried that private indebtedness would also emerge as a problem if the stock market declined, ratios of consumer and mortgage debt had actually increased little in relation to income and had fallen greatly in relation to wealth.<sup>19</sup>

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19. The ratio of outstanding consumer credit to GDP rose from 1987 to 2000:Q3 only from

## **Productivity, Real Wages, and Income per Capita**

Thus far we have examined several manifestations of the American economic miracle of the late 1990s without focussing explicitly on the single most important factor which made all of this possible, namely the sharp acceleration in productivity growth that started at the end of 1995 and that was presumably caused entirely or in large part by the technological acceleration that we have labelled the "New Economy." Figure 7 divides the postwar into three periods using the standard quarterly data published by the Bureau of Labor Statistics (BLS), the "golden age" of rapid productivity growth between 1950:2 and 1972:2, the dismal slowdown period extending from 1972:2 to 1995:4, and the revival period since 1995:4.<sup>20</sup> The top frame shows that for the nonfarm private economy, the revival period registered a productivity growth rate that actually exceeded the golden age by a slight margin, while the middle frame shows that for manufacturing there never was a slowdown, and that the revival period exhibits productivity growth well over double the two previous periods.<sup>21</sup> As a result of the buoyancy of manufacturing, productivity growth outside of manufacturing in the revival period fell well short of the golden age although also exhibited a recovery from the slowdown period. Subsequently we will examine the contrast between a

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14.2 to 14.8 percent, and total outstanding mortgage debt only from 63.2 to 67.8 percent. See *Economic Report of the President*, January 2001, Tables B-77 and B-75, respectively.

20. These precise quarters are chosen because they have roughly the same unemployment rate of about 5.5 percent. The unemployment rate in the final quarter, 2000:1, was 4.1 percent, and we discuss below the possibility that some of the post-1995 productivity acceleration may have been a temporary cyclical phenomenon.

21. The reference above to pessimism based on productivity growth of "barely one percent" during the 1972-95 period refers to data that were revised upward in October, 1999. The average annual growth rate of nonfarm private output per hour during the period 1972:2-1995:4 is 1.42 percent in the newly revised data.

technological acceleration inside manufacturing, primarily in the making of computers, with the absence of any parallel acceleration in technological change outside of manufacturing.

Perhaps no measure of well-being in the U. S. economy has experienced more of a revival than the growth in real wages, for this was the measure of performance for which progress was most dismal during the 1972-95 period. Table 1 compares the growth of nonfarm private output per hour with three measures of real wages, the first two of which deflate hourly compensation by alternative price indexes. Shown in line 2a is real compensation deflated by the deflator for the nonfarm private sector; this measure would grow at the same rate as productivity if the share of compensation in nonfarm private output were constant, which is roughly true in the long run. Line 2b records a slower growth rate of the real consumption wage, slower because during the postwar period the price index of consumption goods and services has increased faster than the price index for nonfarm private output, a difference due primarily to the falling prices of many types of machinery and equipment, especially computers, relative to the prices of consumer services. The most pessimistic measure of all, shown on line 3 of Table 1, is also the most inaccurate, because it counts only part of compensation and uses a deflator (the CPI) which is biased upward to a substantially greater extent than the PCE deflator used on line 2b. The pessimistic measure on line 3 implies that the real wage in 2000:Q3 was only 17.7 percent above that in 1959 (an annual growth rate of only 0.4 percent), whereas the measure on line 2b implies that over the same period the real wage more than doubled (an annual growth rate of 1.78 percent per year). Both measures imply a sharp acceleration of almost two percentage points when the last five years are

compared with the previous eight years.

A more comprehensive measure of well-being, per-capita real income, allows us to illustrate the progress that the U. S. economy has made in the last few years relative to the two other largest industrialized nations, Germany and Japan. Using measures that have been adjusted for the differing purchasing power of other currencies, U. S. per capita income was 25 percent higher than Germany in 1999, compared to margins of 21 percent in 1995, 16 percent in 1990, and 15 percent in 1980. Japan's rapid economic growth continued to 1990 and then stalled, and so it is not surprising that the U. S. margin over Japan widened from 22 percent in 1990 to 31 percent in 1999. However, those who would interpret these comparisons as evidence of U. S. technological success, or even more broadly as evidence that the U. S. has the "best" economic system, are reminded that growth rates of per capita income between these countries are not comparable. Only the U. S. measures the prices of computers with a hedonic price deflator, and this difference in measurement methodology alone over the 1995-99 interval adds about half a percent per year to per-capita U. S. real income growth and, as stated above, subtracts about the same amount from U. S. inflation.<sup>22</sup> But this lack of comparability should not be overstated. Some comparisons of U. S. economic performance with leading foreign nations, e.g., those showing that the U. S. unemployment rate has declined faster and stock market valuations have increased faster, are unaffected by which technique is used to deflate computer expenditures.

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22. In addition the U. S. national accounts were revised in 1999 back to 1959 to include investment in software which is partly deflated with a hedonic price index.

## **Interpreting the Dismal Slowdown Years, 1972-95**

Before turning to a more detailed review of the role of IT in creating the post-1995 U. S. productivity growth revival, we should ask how the U. S. could have experienced such a long period of slow productivity growth between 1972 and 1995, particularly in light of the many structural advantages of the U. S. economy that became apparent after 1995. However, decades of fruitless research on the sources of the post-1972 slowdown suggest that this is the wrong question.

First, the question is wrong because the U. S. slowdown was not unique, but rather with differences in magnitude and timing was shared by the rest of the industrialized world. Second, in a more important sense the question should be flipped on its head to ask not why productivity growth was so slow after 1972, but rather why productivity growth was so fast for so long before 1972.

Every major industrialized country experienced a sharp slowdown in productivity growth after 1973, and the extent of the slowdown in most countries was greater than in the United States. During 1960-73 growth in productivity (ALP) in the 15 countries of the European Union was double and in Japan quadruple that in the U. S. In the 1970s and 1980s productivity growth slowed down everywhere, but later than in the U. S., and by the first half of the 1990s productivity growth in Europe and Japan had converged to that of the U. S. Thus the productivity slowdown was universal in the developed world rather than being unique to the U. S.

The timing of the previous "golden age" of rapid productivity growth had also differed. Following a universal experience of slow productivity growth in the

nineteenth century, the U. S. "golden age" began first, around 1915 and extended until 1972, whereas the golden age in Europe and Japan did not begin in earnest until the postwar reconstruction of the 1950s. Stated another way, the percentage degree of superiority of U. S. per-person GDP and of U. S. productivity began to accelerate around the turn of the century, reached its peak in 1945, and then steadily fell until the early 1990s, when the degree of superiority began to increase again (as discussed above in the context of Figure 8).

The post-1972 slowdown in the U. S., Japan, and Europe can be traced back to the sources of the "golden age" which began around the time of World War I in the United States (Gordon, 2000a). A set of "great inventions" of unprecedented scope and importance, including electricity and the internal combustion engine, had been developed during the Second Industrial Revolution of 1860-1900 and began the process of diffusion through the structure of the economy and society soon after the turn of the century (Gordon, 2000c). The productivity acceleration of the "golden age" occurred as the electric motor revolutionized manufacturing, as the internal combustion engine revolutionized ground transport and allowed the invention of air transport, and as other innovations in chemicals, petroleum, entertainment, communication, and public health transformed the standard of living in the United States between 1900 and the 1950s. In addition to the original advantages of the United States, particularly economies of scale and a wealth of natural resources (Wright, 1990), the dislocation of the two world wars and the turbulent interwar period delayed the diffusion of many of these innovations in Europe and Japan until after 1945, but

then the rich plate of unexploited technology led to a period of rapid catch-up, if not convergence, to the U. S. frontier.

This interpretation explains the post-1972 productivity slowdown as resulting from the inevitable depletion of the fruits of the previous great inventions. The faster productivity growth in Europe and Japan during 1950-72, and the greater magnitude of their slowdowns, and the delayed timing of the slowdown into the 1980s and 1990s, is explained by the late start of Europe and Japan in exploiting the late 19th century "great inventions." Of course this story is too simple to account for the differing fortunes of individual industries; as Europe and Japan recovered and caught up, they did so more in some industries and others, so that by the late 1970s and early 1980s the U. S. automobile and machine tool industries seemed more obviously in the "basket case" category than pharmaceuticals or software.

## **The Role of Information Technology in U. S. Economic Success**

How important has the New Economy and IT revolution been in creating the U. S. productivity revival which appears directly or indirectly to be responsible for most other dimensions of the late-1990s U. S. economic miracle? Fortunately we do not need to explore this question from scratch, since recent academic research has produced a relatively clear answer which is summarized and interpreted in this section. The basic answer is that the acceleration in technical change in computers, peripherals, and semiconductors explains most of the acceleration in overall productivity growth since 1995, but virtually all the progress has been concentrated in the durable manufacturing sector, with surprisingly little spillover

to the rest of the economy.

To provide a more precise analysis we must begin by distinguishing between the growth in output per hour, sometimes called average labor productivity (ALP), from the growth of multi-factor productivity (MFP). The former compares output growth with that of a single input, labor hours, while the latter compares output with a weighted average of several inputs, including labor, capital, and sometimes others, including materials, energy, and/or imports. ALP always grows faster than MFP, and the difference between them is the contribution of "capital deepening," the fact that any growing economy achieves a growth rate of its capital input that is faster than its labor input, thus equipping each unit of labor with an ever-growing quantity of capital.<sup>23</sup>

In all official BLS measures of MFP and in all recent academic research, both labor hours and capital input are adjusted for changes in composition. For labor the composition adjustment takes the form of taking into account the different earnings of different groups classified by age, sex, and educational attainment, and for capital it takes the form of taking into account the different service prices of long-lived structures and different types of shorter-lived producers' equipment. Composition-adjusted growth in labor input is faster than in standard measures of labor input, since educational attainment has been increasing, whereas composition-adjusted growth in capital input is faster than the real stock of capital, since there has been a continuous shift from long-lived structures to shorter-lived equipment, and within equipment to shorter-lived types of equipment, especially computers.<sup>24</sup>

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23. Technically, the growth rate of ALP is equal to the growth rate of MFP plus the growth rate of the capital/labor ratio times the elasticity of output with respect to changes in capital input. Virtually all research on the sources of growth uses the share of capital income in total national income as a proxy for the unobservable elasticity of output to changes in capital input.

24. A short-lived piece of equipment like a computer must have a higher marginal product per dollar of investment to pay for its high rate of depreciation, relative to a long-lived hotel or office building. Composition-adjusted measures of capital input reflect differences in the marginal

## The "Direct" and "Spillover" Effects of the New Economy

How have computers and the New Economy influenced the recent productivity growth revival? Imagine a spontaneous acceleration in the rate of technological change in the computer sector, which induces a more rapid rate of decline in computer prices and an investment boom as firms respond to cheaper computer prices by buying more computers.<sup>25</sup> In response, since computers are part of output, this acceleration of technical change in computer production raises the growth rate of MFP in the total economy, boosting the growth rate of ALP one-for-one. Second, the ensuing investment boom raises the "capital deepening" effect by increasing the growth rate of capital input relative to labor input and thus increasing ALP growth relative to MFP growth.

In discussing the New Economy, it is important to separate the computer-producing sector from the computer-using sector. No one denies that there has been a marked acceleration of output and productivity growth in the production of computer hardware, including peripherals.<sup>26</sup> The real issue has been the

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products of different types of capital and thus place a higher weight on fast-growing components like computers and a lower weight on slow-growing components like structures.

25. As stated above, in the U. S. national accounts computer prices are measured by the hedonic regression technique, in which the prices of a variety of models of computers are explained by the quantity of computer characteristics and by the passage of time. Thus the phrase in the text "decline in computer prices" is shorthand for "a decline in the prices of computer attributes like speed, memory, disk drive access speed and capacity, presence of a CD-ROM, etc."

26. In this paper we emphasize computer hardware, rather than the universe of computer hardware, software, and telecommunications equipment, because the BEA deflators for software and telecommunications equipment are problematic, exhibiting implausibly low rates of price

response of productivity to massive computer investment by the 96 percent of the economy engaged in using computers rather than producing them.<sup>27</sup> If the only effect of the technological breakthrough in computer production on the non-computer economy is an investment boom that accelerates the growth rate of capital input, then non-computer ALP growth would rise by the capital-deepening effect, but there would be no increase in non-computer MFP growth. Let us call this the "direct" effect of the New Economy on the non-computer sector. Sometimes advocates of the revolutionary nature of the New Economy imply that computer investment has a higher rate of return than other types of investment and creates "spillover" effects on business practices and productivity in the non-computer economy; evidence of this "spillover" effect would be an acceleration in MFP growth in the non-computer economy occurring at the same time as the technological acceleration in computer production.

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decline, as argued by Jorgenson and Stiroh (2000).

27. In 1999 nominal final sales of computers and peripherals plus fixed investment in software represented 3.5 percent of nominal GDP in the nonfarm nonhousing private business economy. Thus the "non-computer part of the economy" represents 96.5 percent of nonfarm nonhousing private business output. Final sales of computer hardware is an unpublished series obtained from Christian Ehemann of the BEA; the other series in this calculation appear in the *Economic Report of the President*, February 2000, Tables B-10 and B-16.

## **The Role of IT in the Productivity Growth Revival**

What is the counterpart of the New Economy in the official output data?

The remarkable event which occurred at the end of 1995 was an acceleration of the rate of price change in computer hardware (including peripherals) from an average rate of -12 percent during 1987-95 to an average rate of -29 percent during 1996-98.<sup>28</sup> Computers did not become more important as a share of dollar spending in the economy, which stagnated at around 1.3 percent of the nonfarm private business economy. The counterpart of the post-1995 acceleration in the rate of price decline was an acceleration in the rate of technological progress; apparently the time cycle of Moore's Law shortened from 18 months to 12 months at about the same time.<sup>29</sup>

We now combine two different academic studies to assess the role of IT in contributing to the economywide acceleration in ALP and MFP growth since 1995.

First, we use the recent results of Oliner and Sichel (2000, 2001) to compute the contribution of computers and semiconductors both to capital deepening and to the MFP acceleration in the overall economy. Second, we summarize my recent study (Gordon, 2000b) that adds two elements to the work of Oliner and Sichel.

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28. The numbers in the text refer to the annual rate of change of the BEA implicit deflator for investment in computers and peripherals between 1995:4 and 1998:4. One way of dramatizing the rate of price decline is to translate it into the ratio of performance to price when 1999:Q4 is compared with 1993:Q4. The BEA's implicit deflator for computer final sales implies an improvement over that six-year period by a factor of 5.2. Improvements in performance-price ratios for individual computer components are substantially larger, by a factor of 16.2 for computer processors, 75.5 for RAM, and 176.0 for hard disk capacity. See "Computers, then and now," *Consumer Reports*, May, 2000, p. 10, where the published reported comparisons in 1999 dollars have been converted to nominal dollars using the Consumer Price Index.

29. Moore's law states that the number of transistors on a single computer chip doubles every eighteen months. The reduction in time from eighteen to twelve months is based on a conversation between Gordon Moore and Dale W. Jorgenson, related to the author by the latter.

First, it uses official BLS data to "strip" the overall economy of the contribution of the ALP and MFP acceleration that is located within durable manufacturing, so that we can assess the extent of any spillover of IT in the 88 percent of the economy located outside of durables. Second, it updates my previous work on the cyclical behavior of productivity, which shows that there is a regular relationship between growth in hours relative to the trend in hours, and growth in output relative to the trend in output. We can use this statistical relationship based on data going back to the 1950s to estimate the trend of output and productivity growth during 1995-2000, given the trend in hours, and thus extract the remaining cyclical component, i.e., the difference between actual productivity growth and trend productivity growth.<sup>30</sup>

The results displayed in Table 2 allow us to assess the direct and spillover effects of computers on output per hour and MFP growth during the period between 1995:Q4 and 2000:Q4. The first column refers to the aggregate economy, i.e., the NFPB sector including computers. Of the actual 2.86 percent annual growth of output per hour, 0.40 is attributed to a cyclical effect and the remaining 2.46 percent to trend growth, and the latter is 1.04 points faster than the 1972-95 trend. How can this acceleration be explained? A small part on lines 6 and 7 is attributed to changes in price measurement methods and to a slight acceleration in the growth of labor quality.<sup>31</sup> All of the remaining 0.89 points can be directly

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30. The equations estimated are those developed in Gordon (1993).

31. The price measurement effect consists of two components. While most changes in price measurement methods in the CPI have been backcast in the national accounts to 1978, one remaining change – the 1993-94 shift in medical care deflation from the CPI to the slower-growing PPI – creates a measurement discontinuity of 0.09 percent. The fact that other measurement

attributed to computers. The capital-deepening effect of faster growth in computer capital relative to labor in the aggregate economy accounts of 0.60 percentage points of the acceleration (line 9a) and a 0.30-point acceleration of MFP growth in computer and computer-related semiconductor manufacturing account (line 10) sum to an explanation of 0.90 points, compared to the 0.89 acceleration in trend that needs to be explained. Because non-computer capital makes a negative contribution of -0.23 points to the capital-deepening effect, there is a remaining 0.22 points left over as the residual, which represents faster MFP growth outside of computer manufacturing.

To locate where this remaining MFP growth revival has occurred, column (2) of Table 2 repeats the exercise for the 88 percent of the private economy outside of durable manufacturing. The MFP revival at the bottom of column (2) is a trivial 0.07 percent outside of durable manufacturing, and the difference between columns (1) and (2) indicates that durable manufacturing other than the production of computers accounts for the remaining 0.15 percent acceleration of MFP growth in the private economy.

Thus the verdict on the "New Economy" is decidedly mixed. The productivity revival is impressive and real, and most of it is structural rather than cyclical. The productivity revival has spilled over from the production of computers to the use of computers. The evident effect of new technologies in reducing transaction costs and facilitating a surge in trading volumes in the

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changes were carried back to 1978 rather than 1972 creates a further discontinuity of 0.05 when the full 1972-95 period is compared to 1995-99. The acceleration in labor quality growth reflects the fact that labor quality growth during 1972-95 was held down by a compositional shift toward female and teenage workers during the first half of that period.

securities industry is one of many ways in which the use of computers has contributed to the productivity revival, and all of this fruitful activity is encompassed in the 0.60 percent per year contribution of "capital deepening" listed on line 9a of Table 2.

However the productivity revival is narrowly based in the production and use of computers. There is no sign of a fundamental transformation of the U. S. economy. There has been no acceleration of MFP growth outside of computer production and the rest of durable manufacturing. Responding to the accelerated rate of price decline of computers that occurred between 1995 and 1998, business firms throughout the economy boosted purchases of computers, creating an investment boom and "capital deepening" in the form of faster growth of capital relative to labor. But computer capital did not have any kind of magical or extraordinary effect — it earned the same rate of return as any other type of capital.

The dependence of the U. S. productivity revival on the production and use of computers waves a danger flag for the future. Consider the possibility that the accelerated 1995-98 29 percent rate of price decline for computers does not continue. Already in the year ending in 2000:Q4 the rate of price decline slowed from 29 to 12 percent, the same as between 1987 and 1995. If in response the growth rate of computer investment were to slow down to a rate similar to that before 1995, then the main source of the productivity revival identified by Oliner and Sichel (2000, 2001) would disappear, and with it much of the U. S. economic miracle.

## **The Puzzling Failure of the Internet to Shift the Demand Curve for Computers**

While the invention of the Internet is usually treated as revolutionary, a simple analysis of the supply and demand for computer hardware may suggest a more limited role for the Internet. We have already seen that the rate of decline of prices for computer hardware, including peripherals, accelerated sharply after 1995. This fact is shown in the top frame of Figure 9, which plots the price and quantity of computer characteristics since 1960. The implicit price deflator for computer hardware, including peripherals, declined from 61,640 in 1961 to 33 at the end of 2000 (with a base 1996 = 100), for an annual rate of decline of 19.4 percent per annum. There has been a corresponding increase in the quantity of computer attributes, and both the rate of price decline and quantity increase accelerated after 1995 (as indicated by the increasing spaces between the annual price and quantity observations starting in 1995).

While the rate of price change has varied over time, the notable feature of rapid price decline does not distinguish the New Economy from the 1950-80 interval dominated by the mainframe computer or the 1980-95 interval dominated by the transition from mainframe to PC applications prior to the invention of the Internet.<sup>32</sup> Throughout its history, the economics of the computer has featured a steady downward shift in the supply curve of computer attributes at a rate much faster than the upward shift in the demand for computer services. In fact, the

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32. Existing computer price deflators fail to take account of the radical decline in the price per calculation that occurred in the transition from mainframes to PCs (which have been studied only separately, not together). Gordon (1990, p. 239) calculates that the annual rate of price decline between 1972 and 1987 would have been 35 percent per annum rather than 20 percent per annum if this transitional benefit had been taken into account. This consideration further reduces the uniqueness of technological advance created by the New Economy.

story is often told with a theoretical diagram like the bottom frame of Figure 9, in which the supply curve slides steadily downwards from  $S_1$  to  $S_2$  with no shift in the demand curve at all.<sup>33</sup> Ignoring the possibility of a rightward shift in the demand curve from  $D_1$  to  $D_2$  (we return to this possibility below), the second distinguishing feature of the development of the computer industry is the unprecedented speed with which diminishing returns set in; while computer users steadily enjoy an increasing amount of consumer surplus as the price falls, the declining point of intersection of the supply curve with the fixed demand curve implies a rapid decline in the marginal utility or benefit of computer power.

The accelerated rate of price decline in computer attributes has been accompanied since 1995 by the invention of the Internet.<sup>34</sup> In perhaps the most rapid diffusion of any invention since television in the late 1940s and early 1950s, by the end of the year 2000 the percentage of American households hooked up to the Internet reached 50 percent.<sup>35</sup> Surely the invention of web browsers and the explosive growth of e-commerce should be interpreted as a rightward shift in the demand curve in the bottom frame of Figure 9 from  $D_1$  to  $D_2$ . Such a rightward shift in the demand curve would imply an increase in the benefits provided by all

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33. Three examples of this graph applied to computers exhibiting no shift in the demand curve are Brynjolfsson (1996, p. 290), Gordon (1990, p. 46) and Sichel (1997, p. 17). The supply curves in this graph have been drawn as horizontal lines, both to simplify the subsequent discussion of consumer surplus and because there is no evidence of a rising marginal cost of producing additional computer speed, memory, and other characteristics at a given level of technology.

34. Here to simplify the presentation we will take the Internet as being synonymous with the World Wide Web and the invention of web browsers, although the use of the Internet for e-mail, at least in the academic and scientific community, dates back at least to the early 1980s.

35. This projection is made by Henry Harteveldt, Senior Analyst at Forrester Research, in communications with the author.

computers, both old and new.<sup>36</sup>

However, if there had been a discontinuous rightward shift in the demand curve for computer hardware due to the spread of the Internet, we should have observed a noticeable flattening of the slope of the price-quantity relationship in the top frame of Figure 9, as the rate of increase of quantity accelerated relative to the rate of decline in price, but we do not. The rate of change of price and quantity both accelerate after 1995 (as indicated by the greater spacing between annual observations) but the slope does not change appreciably, suggesting that the spread of the Internet is a byproduct of rapid technological change that is faster than in previous decades but not qualitatively different in the relationship between supply and demand than earlier advances in the computer industry.

The data on the price and quantity of computer characteristics have previously been used to "map out" the demand curve (Brynjolfsson, 1996, p. 290). In fact, the slope of the price-quantity relationship was appreciably flatter during 1972-87 than during 1987-95 or 1995-99. If the demand curve has not shifted, the inverse of these slopes is the price elasticity of demand, namely -1.96, -1.19, and -1.11 in these three intervals, which can be compared with Brynjolfsson's (1996, p. 292) estimated price elasticity of -1.33 over the period 1970-89. The apparent decline in the price elasticity is consistent with the view that the most important uses of computers were developed more than a decade into the past, not currently.

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36. In terms of elementary economics, there is an increase in the consumer surplus associated with the lower supply curve  $S_2$  from the triangle  $JP_2B$  to the larger triangle  $KP_2C$ .

## **The New Economy and the Sources of Technological Change**

Our macroeconomic analysis has reached the paradoxical conclusion that the New Economy, interpreted as an acceleration of the rate of price decline of computer hardware and peripherals, is responsible for most of the acceleration of U. S. ALP and MFP growth, at least the part that cannot be attributed to a temporary cyclical effect. In the major portion of durable manufacturing devoted to producing goods other than computer hardware there appears to have been considerable technical dynamism, with a substantial acceleration in MFP growth and no apparent contribution of temporary cyclical effects. Yet there does not appear to have been a revival in MFP growth outside of durable manufacturing, and the acceleration of labor productivity growth in the rest of the economy seems to be attributable to the benefits of buying more computers, not any fundamental technological advance that goes beyond a return on investment in computers similar to the return on investment in any other type of capital equipment.

Albeit narrowly based in computer hardware, at least in the official statistics, the apparent "rupture" or discontinuity in the rate of technical change in the mid-1990s forces to inquire as to its sources and lessons for understanding the economic history of the U. S. and other nations. America is now almost universally believed to have surged to the forefront in most of the IT industries, and even a substantial correction of the stock market will still leave American hi-tech companies dominating the league table of the world's leaders in market capitalization. While our detailed quantitative analysis of the U. S. productivity revival has emphasized computer hardware, our overview of the American performance focusses more broadly on software, telecommunications, pharmaceuticals, and biotech.

## **National Technological Leadership: General Considerations**

The mid-1990s discontinuity of technical change in the United States was not predicted in advance, although its significance was spotted almost immediately by *Business Week* and some other astute observers.<sup>37</sup> A decade ago it was "Japan as Number One", and briefly the market value of Japanese equities exceeded that of American equities. Rosenberg (1986, p. 25) perceptively generalizes about the difficulty of forecasting the consequences of inventions in advance: "A disinterested observer who happened to be passing by at Kitty Hawk on that fateful day in 1903 might surely be excused if he did not walk away with visions of 747s or C-5As in his head." The great success of Japanese firms in dominating many leading technologies in the 1980s did not appear to give them any head start in dominating the new technologies of the 1990s. Rosenberg points to the failure of carriage makers to play any role in the development of the automobile, or even the failure of steam locomotive makers to participate in the development of the diesel locomotive. Thus it is perhaps not surprising that Japanese electronics companies did not participate to any great extent in the particular interplay of chip-making technology and software development that created the Internet and the post-1995 technical acceleration in computer hardware. We will return below to some of the possible causes of American

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37. Most notably Edward Yardeni, now the Chief Economist of Deutsche Banc Alex Brown, who early in the 1990s predicted both the stock market boom and the revival of productivity growth.

leadership in the technical developments of the 1990s.

Many inventions initially created to solve a narrow problem (for instance, the steam engine was initially invented to pump water out of flooded mines) turn out to have widespread further uses that are not initially foreseen. Major inventions spawn numerous complementary developments; while the initial motivation for the internal combustion engine was to improve the performance-to-weight ratio of the steam engine, it made possible not only motor transport and air transport, but such complementary developments as the suburb, supermarket, superhighway, and the tropical vacation industry. In turn, the complementary inventions raise the consumer surplus associated with the invention, and this may continue for a long time. The invention of the Internet is just one of many byproducts of the invention of electricity that raise the consumer surplus of that initial major invention.<sup>38</sup>

The literature on technology distinguishes between the initial invention and its subsequent development and diffusion. A longstanding puzzle in the retardation of British economic growth after the 1870s is the fact that many inventions initially made by British inventors were brought to commercial success in the U. S., Japan, and elsewhere. This issue of who captures the fruits of innovation suggests that the British were not alone in losing out. The U. S.

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38. An explicit analysis of the effect of complementary inventions on the consumer surplus of the initial invention is provided by Bresnahan and Gordon (1997, pp. 7-11).

invention of videotape was followed by exploitation of the consumer VCR market that was almost entirely achieved by Japanese companies. The Finnish company Nokia took over leadership in mobile phones from Motorola. Within any economy there are winners and losers as upstart companies (Intel, Microsoft) seize the advantage in developing technology while leaving older competitors (IBM, Wang, Digital Equipment, Xerox) behind.

While predicting technological developments in advance is exceedingly difficult, there is an ample literature which points to particular national characteristics that help to explain, at least in retrospect, why particular inventions and industries came to be dominated by particular countries.<sup>39</sup> Perhaps the one generalization that spans most industries is the role of the product cycle. No matter what the causes of initial national leadership, technology eventually diffuses from the leading nations to other nations that may have lower labor costs. It is beyond the scope of this discussion to explain why some nations, e.g., Korea, Taiwan, and Singapore, seem to have done so much better than other nations, e.g., Brazil or India, in combining technological duplication with an advantage, at least initially, in labor costs, in industries ranging from automobiles to chip, computer, and disk-drive manufacturing.

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39. The generalizations in the next several paragraphs select among the more important points made by Mowery and Nelson (1999a).

## **Sources of U. S. Technological Leadership**

**1. The Traditional Sources of U. S. Advantage.** According to the standard data compiled by Maddison and others, the level of income per person in the United States moved ahead of that in the United Kingdom in the late nineteenth century and has remained in first place among the major developed nations ever since. An extensive literature on the sources of U. S. superiority (e.g., Wright, 1990) identifies national advantages both in the supply of resources and in national characteristics of demand. The U. S. achieved initial leadership in petrochemicals in part because of its abundant supply of cheap domestic petroleum, while its leadership in machine tools was the result of its early adoption of mass production methods, which in turn reflected its relative scarcity of labor and its large internal market. In turn mass production, together with long distances, cheap land, and the low density of urban development help to explain why the U. S. achieved such an enormous early lead in automobile production and ownership in the 1920s. In turn the mass market for automobiles fed back into a rapidly increasing demand for gasoline and stimulated further developments in petroleum and petrochemical manufacturing.

However, it is less clear that America's large domestic market provided a universal source of advantage throughout the history of technological development over the last two centuries. Between 1870 and 1914 flows of goods, capital, and immigrants were notably free, and trade could create international markets on the scale of the U. S. domestic markets, as demonstrated by German dominance in chemicals. After 1960 Japan rose to prominence and even domination in one industry after another, with export markets providing the scale that was lacking, at least initially, at home.

**2. Educational Attainment and University Research.** Close integration of industrial R&D and university research is credited with German domination of the chemical products industry between the 1870s and early 1920s, as well as German and Swiss leadership in the development of pharmaceuticals in the early part of the 20th century. More generally, a rise in educational attainment is one of the sources of rising output per hour. While the first cited role of the education system in technological development is the rise of the German chemical industry after 1870, a set of relatively uncoordinated policies at the state and local level resulted in the U. S. achieving the first universal secondary education between 1910 and 1940 (Goldin, 1998) and the highest rate of participation in college education after World War II.

Even in the dismal days of American pessimism during the years of the productivity slowdown, it was widely recognized that America's private and state-supported research universities were its most successful export industry, at least as measured by its lead over other countries and its appeal for students from the rest of the world. The interplay among these research universities, government research grants, and private industry was instrumental in achieving American leadership in the IT industry, and it was no coincidence that Silicon Valley happened to be located next to Stanford University or that another concentration of IT companies in the hardware, software, and biotech industries was located in the Boston area near M.I.T. and Harvard.

A U. S. educational advantage of possible importance is its early development of the graduate school of business and its continuing near-monopoly

in this type of education. The mere existence of business schools did not provide any solution to the productivity slowdown of the 1970s and 1980s, and indeed the ongoing superiority of Japanese firms in automobiles and consumer electronics elicited the cynical joke in those years that "the secret advantage of the Japanese manufacturers is that they have no world-class business schools." While U. S. business schools were indeed weak in teaching such specialities as manufacturing production and quality control, they excelled in finance and general management strategy. These skills came into their own in the 1990s and interacted with the rise of the venture capital industry and internet start-up companies; in the United States more than elsewhere there was a ready supply of thousands of well-educated MBAs, both knowledgeable about finance and receptive to a culture of innovation and risk-taking. Further, U. S. business schools have provided a wealth of talent to further develop U. S. worldwide dominance in investment banking, accounting, and management-consulting firms.

**3. Government-funded Military and Civilian Research.** Ironically for a country that has been suspicious of government involvement, it is the United States that appears to demonstrate the closest links between government policy and technological leadership. Research support from the National Institutes of Health is credited with postwar American leadership in pharmaceuticals and biomedical research. Defense-funded research and government-funded grants is credited with the early emergence of American leadership in semiconductors, computers, software, biotech, and the Internet itself. Government antitrust policy

is credited with the emergence of a software industry largely independent of computer hardware manufacturers.

There are notable differences between the U. S. method of supporting higher education and research and that found in European countries like France, Germany, and the U. K. First, the U. S. mix of private universities and those financed at the state and local level promotes competition and allows the top tier of the private university sector the budgetary freedom to pay high salaries, fund opulent research labs, and achieve the highest levels of quality, in turn attracting many top faculty members and graduate students from other countries. Second, much of U. S. central government research support is allocated through a peer-review system that favors a meritocracy of young, active researchers and discourages elitism and continuing support for senior professors whose best ideas are in the past. In Europe a much larger share of central government support to universities and research institutes goes to general budgetary support that tends to result in a more equal salary structure less prone to reward academic "stars" and also relies less on the periodic quality hurdle imposed by peer review. This set of differences is in addition to specific national shortcomings, e.g., the hierarchical dominance of senior research professors in Germany.

**4. Other Government Policies.** Explicit government policies to encourage the development of specific industries by trade protection and financial subsidies may have been successful in helping to accelerate the rise of Japan and Korea to industrial success, but they have been less successful in the United States and Europe and indeed may have backfired in Japan in the past decade. The

relevance of particular government policies, from protection to defense spending to antitrust, differs sufficiently across industries as to discourage generalizations.

In the industries of most concern to us in this paper — semiconductors, computer hardware, and computer software, the most important aspect of public policy appears to have been the relatively unfocussed support of research and training by the U. S. government. The literature on the American resurgence in semiconductor production as well as its continuing dominance in software also emphasizes the role of private enforcement of intellectual property rights and regulation of licensing agreements (see Bresnahan and Melerba, 1999, and Mowery, 1999). The U. S. pharmaceutical industry initially gained an advantage through massive government support during World War II, health-related research support during most of the postwar period, and a long tradition of strong U. S. patent protection — patent protection was also strong in parts of Europe, but not in Italy and also not in Japan. U. S. drug companies also were able to make high profits, much of which was reinvested in R&D, as a result of high rents earned in the face of a fragmented health care system with no attempt by the government to place price or profit ceilings on drug companies (see Pisano's paper in this volume).

Another set of U. S. policies could be interpreted as "enforcement of benign neglect." The U. S. government took no action to arrest the erosion of state sales tax revenues as internet e-commerce merchants sold items without charging any sales tax to customers. In effect, the freedom of e-commerce transactions from the burden of sales taxes amounted to government subsidization of shipping charges, since for e-commerce these usually amounted to roughly the same surcharge on listed prices as sales taxes at traditional bricks and mortar outlets. The U. S. government also maintained a zero-tariff regime for trade in electronic components, fostering large trade flows in both directions and a large U. S. trade deficit in IT manufacturing.

**5. Capital Markets.** In the 1980s American capital markets seemed to be a source of American industrial weakness, with their emphasis on short-run profit maximization, and there was much envy of the access of Japanese firms to low-cost bank capital that played a role in the temporary period of Japanese domination of the semiconductor industry. But the American capital market turned out to be a blessing in disguise. A long tradition of government securities regulation that forced public disclosure and information and of access of equity research analysts to internal company information had fostered a large and active market for public offerings, and this together with the relatively recent emergence of the venture capital industry provided ample finance for start-up companies once the technological groundwork for the Internet was laid in the mid-1990s.<sup>40</sup> The paper by Lerner in this volume identifies a critical policy change as fostering the relatively recent rise of the U. S. venture capital industry, namely a ruling that allowed pension funds to invest in venture capital firms.

**6. Language and Immigration.** The literature on technological leadership omits two sources of American advantage that are surely not insignificant. While language has little to do with domination in computer hardware (where indeed many of the components are imported), it is surely important for the American software industry that English long ago became the world's leading second

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40. As usual there are interconnections between the various sources of American advantage. For instance, the best U. S. private universities have been a critical source of U. S. technological leadership and their wealth and power has been further augmented by their recent investments in U. S. venture capital firms. For instance in 1999 Harvard made roughly a 150 percent return on its venture capital investments and a return of over 40 percent on its entire endowment which now totals almost \$20 billion.

language in addition to being spoken as a first language by a critical mass of the world's educated population. Another oft-neglected factor that should be discussed more often is the longstanding openness of the United States to immigration and the role of immigrants from India, East Asia, and elsewhere in providing the skilled labor that has been essential to the rise of Silicon Valley.

Another aspect of American advantage and disadvantage is also perhaps too little discussed. The technology literature summarized above places heavy emphasis on the unique role of American research universities in providing a competitive atmosphere geared to the attraction of the best faculty performing the best research. Yet every year another set of test results is announced in which Americans score far down the league tables in math and science when compared to numerous countries in Europe and Asia. Those who wring their hands about the state of American elementary and secondary education might better spend their energies lobbying Congress to increase the immigration quotas for highly educated individuals with skills in those areas where some Americans are weak, science and engineering. And those who would argue that loosening of high-skilled quotas should occur at the cost of a reduction in low-skilled quotas are urged to consider the many benefits of immigration in general, including the provision of new workers to ease the strain of overly tight labor markets, the revitalization of many central cities, and the postponement forever of any so-called Social Security "crisis."

## **Comparisons with Other Countries**

In most comparisons among the leading industrialized nations Britain (and sometimes Canada) occupy a central ground between the extremes of American exceptionalism and the opposite tendencies of the continental Europeans and Japanese, whether concerning the level of unemployment, employment protection or the lack thereof, the degree of inequality, and the extent of government spending. Yet in comparing the extent of American technological leadership with other countries, the story is not one of extremes, and the balance of advantage varies widely by industry.

Americans dominate most strongly in microprocessors and in computer software. As documented in the paper by Langlois in this volume, the extent of Intel's domination of the worldwide market for microprocessors is perhaps unprecedented in industrial history, and the same could be said for Microsoft. However, the U. S. advantage in computer hardware is qualified by the role of Asian countries in providing components like memory chips, hard drives, and laptop screens. In fact the United States runs a large trade deficit in computer hardware and peripherals, both because of component imports from Asia and because a substantial share of production by American companies like Intel and Dell takes place not just at home but also in foreign countries like Ireland. In mobile telephones the U. S. has been handicapped by regulation that favored too much competition and allowed multiple standards, thus allowing the dominant producers of GSM equipment and infrastructure (Nokia and Ericsson) to run away with the worldwide mobile phone market. The American pharmaceutical industry also faces strong competition from British, German, and Swiss firms.

Nevertheless, several sources of systemic U. S. advantage stand out, most

notably the mixed system of government- and private-funded research universities, the large role of U. S. government agencies providing research funding based on a criterion of peer review, and the strong position in a worldwide perspective of U. S. business schools and U. S.-owned investment banking, accounting, and management-consulting firms. By comparison Germany seems particularly weak in its failure to reform its old-fashioned hierarchical university system, its bureaucratic rules that inhibit start-up firms, its reliance on bank debt finance, and its weakness in venture capital and equity finance (see the Siebert and Stolpe paper in this volume). France suffers from overcentralized government control, a system of universities and research institutions which places more emphasis on rewarding those with an elite educational pedigree rather than those currently working on the research frontier, and a culture (with its frequent strikes by farmers and government workers) which is relatively hostile to innovation and change (see the Messerlin paper in this volume).

Until its structural reforms and privatizations of the 1980s and 1990s, Britain shared with France and Germany a labor market dominated by strong unions. While the strong unions are gone, Britain continues to suffer from handicaps that date back a century or more, including a shortfall of technical skills among manual workers and a lack of graduate management training and business-oriented culture among highly educated workers. Where Britain does well, as in investment banking or as a destination of inward foreign investment, it relies on a relatively narrow set of advantages, including the traditional role of the City of London as a financial center, and the same advantage that the English language provides, i.e., as a comfortable place for Asian firms to build plants, to the United States, Canada, Ireland, Australia, and other parts of the former British Empire.

## Conclusion

The outstanding performance of the American economy in the late 1990s raises the danger of a resurgent American triumphalism, perhaps symbolized by an imaginary *Arc de Triomphe* erected over Sand Hill Road at the border between Palo Alto and Menlo Park, CA, the heart of the venture capital industry that has funded many of the start-up companies of the New Economy. But while the disastrous aftermath of the glorious inflation-free growth of 1927-29 is very unlikely to follow the glowing economic conditions of 1997-2000, we should be careful about extrapolating the successes of the recent past or in pretending that success has been universal.

While the fruitful collaboration of government research funding, world-leading private universities, innovative private firms, and a dynamic capital market set the stage for American domination of the industries that constitute the New Economy, these preconditions did not prevent the U. S. from experiencing the dismal 1972-95 years of the productivity growth slowdown and near-stagnation of real wages, and they do not give the U. S. an advantage in many other industries. A quarter century after the invasion of Japanese auto imports, the quality rankings of automobiles still are characterized by a bimodal distribution in which Japanese and German nameplates (even those manufactured in the U. S.) dominate the highest rankings and American nameplates dominate the lowest.<sup>41</sup> The U. S. shows no sign of regaining leadership in the manufacturing of computer peripherals or machine tools.

The rapid rate of output growth in the American economy between 1995 and 2000 was facilitated by two unsustainable "safety valves," the steady decline

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41. See *Consumer Reports*, April, 2000, and the latest J. D. Powers initial quality rankings.

in the unemployment rate and the steady increase in the current account deficit. Since neither can continue forever, growth in both output and in productivity are likely to be less in the next half-decade than in the last, and the likely adjustment in the stock market may cause at least part of the American economic miracle to unravel. Further, a basic finding of my recent research as summarized earlier in this paper (see Table 2 above) is that the dominant source of the post-1995 productivity growth revival was an acceleration in the growth of computer investment, which boosted productivity growth both through the direct effect of making the computers and the indirect benefits of using the computers. If the growth of computer investment should slow down in the next half-decade to a rate more similar to the years before 1995 than the years since then, half or more of the productivity growth revival might disappear.

This paper has emphasized the production and use of computers and the spread of the world wide web as the main channel by which technology has contributed to the U. S. productivity revival and economic miracle of the late 1990s. Much less has been said about telecommunications and biotechnology. Telecom connections have been essential to the networking effects of the web and to creating the demand for ever-more powerful computer hardware. But existing government price deflators for telecom equipment do not decline at anything like the rates registered by computer hardware, and so, simply as a matter of arithmetic, the producers of telecom equipment do not contribute to the growth of real GDP and productivity in amounts remotely approaching the contribution of computer hardware.

For biotechnology the measurement failure is more complete and harder to repair. Benefits of biotech innovations in prolonging life or reducing pain are not included in GDP and are simply missed in our national accounts and productivity

statistics. Advances in medical technology, to the extent that they are produced by the government or in the nonprofit hospitals and universities, are excluded by definition from the core sector covered by the productivity statistics, namely the nonfarm private business sector. Like many benefits of the "New Economy," biotech research may boost consumer welfare without having any measurable impact on productivity. But this is an old story – the great old inventions like electricity and the internal combustion engine delivered unparalleled increases in consumer welfare in the early and mid 20th century as electric light lengthened the day, consumer appliances reduced household drudgery, air conditioning made the South habitable, and motor cars, not to mention airplanes, produced flexible travel patterns and large savings of time. The fruits of innovation in telecom and biotech are both wondrous and partly unmeasured, and exactly the same could be said with even greater emphasis of all the great inventions dating back to the dawn of the first industrial revolution in the late 18th century.

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**Table 1**

**Output per Hour and Alternative Real Wage Concepts,  
Nonfarm Private Business Sector, Alternative Intervals 1959-2000:4  
(Percentage Growth Rate at Annual Rate)**

	<b>1959- 1972 (1)</b>	<b>1972- 1987 (2)</b>	<b>1987- 1995 (3)</b>	<b>1995- 1999:4 (4)</b>
<b>1. Output per Hour</b>	2.83	1.52	1.38	2.87
<b>2. Real Compensation per Hour</b>				
<b>a. Deflated by Nonfarm Nonhousing Deflator</b>	3.14	1.55	0.92	2.66
<b>b. Deflated by Personal Consumption Deflator</b>	2.99	1.23	0.38	2.26
<b>3. Average Hourly Earnings deflated by Consumer Price Index</b>	1.87	-0.66	-0.56	1.24

*Sources:* *Economic Report of the President*, January 2001, Tables B-7, B-10, B-11, B-47, and B-49.

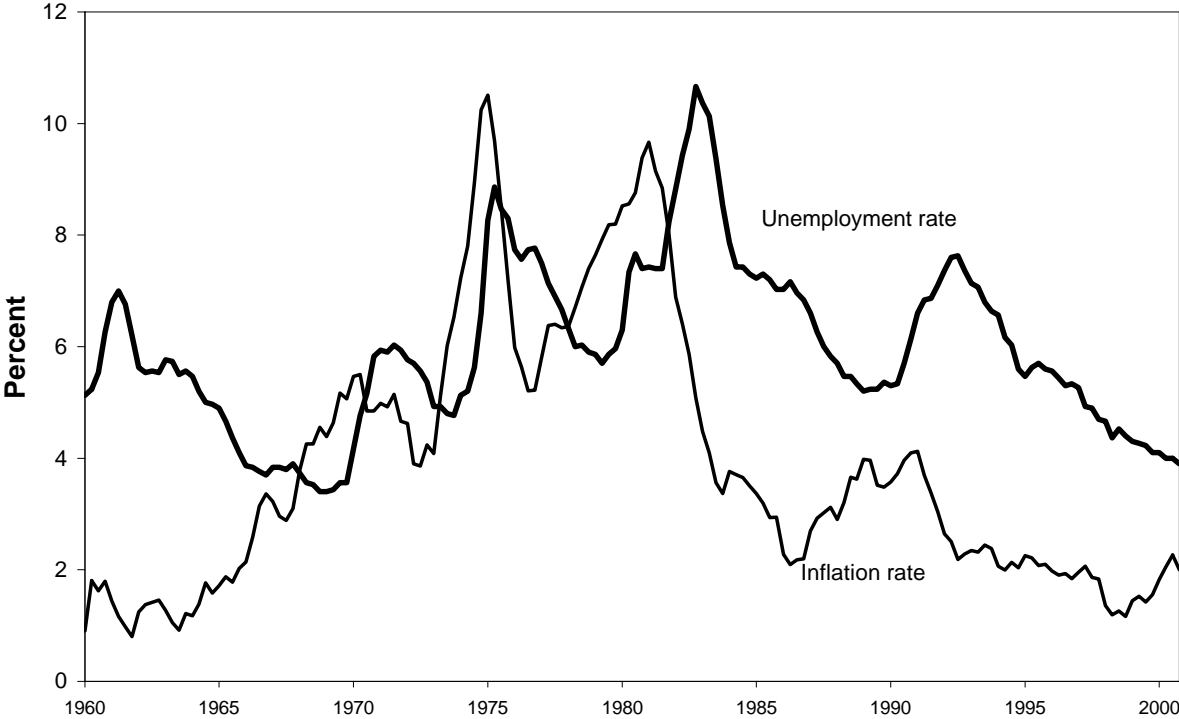
**Table 2**

**Decomposition of Growth in Output Per Hour, 1995:4-2000:4,  
Into Contributions of Cyclical Effects and  
Structural Change in Trend Growth  
(Percentage Growth Rates at Annual Rate)**

	<b>Nonfarm Private Business (1)</b>	<b>NFPB Excluding Durable Manufacturing (2)</b>	<b>Effect of Durable Manufacturing (1)-(2)</b>
<b>1. Actual Growth</b>	2.86	2.20	0.66
<b>2. Contribution of Cyclical Effect</b>	0.40	0.48	-0.08
<b>3. Growth in Trend (line 1 - line 2)</b>	2.46	1.72	0.74
<b>4. Trend, 1972:2 - 1995:4</b>	1.42	1.13	0.29
<b>5. Acceleration of Trend (line 3 - line 4)</b>	1.04	0.59	0.45
<b>6. Contribution of Price Measurement</b>	0.14	0.14	0.00
<b>7. Contribution of Labor Quality</b>	0.01	0.01	0.00
<b>8. Structural Acceleration in Labor Productivity (line 5 - 6 - 7)</b>	0.89	0.44	0.45
<b>9. Contribution of Capital Deepening</b>	0.37	0.37	0.00
<b>a. Information Technology     Capital</b>	0.60	0.60	0.00
<b>b. Other Capital</b>	-0.23	-0.23	0.00
<b>10. Contribution of MFP Growth in Computer and Computer- Related Semiconductor Manufacturing</b>	0.30	-0.00	0.30
<b>11. Structural Acceleration in MFP (line 8 - 9 - 10)</b>	0.22	0.07	0.15

Sources: Updated version of Gordon (2000b, Table 2). Lines 9 and 10 come from Oliner and Sichel (2001).

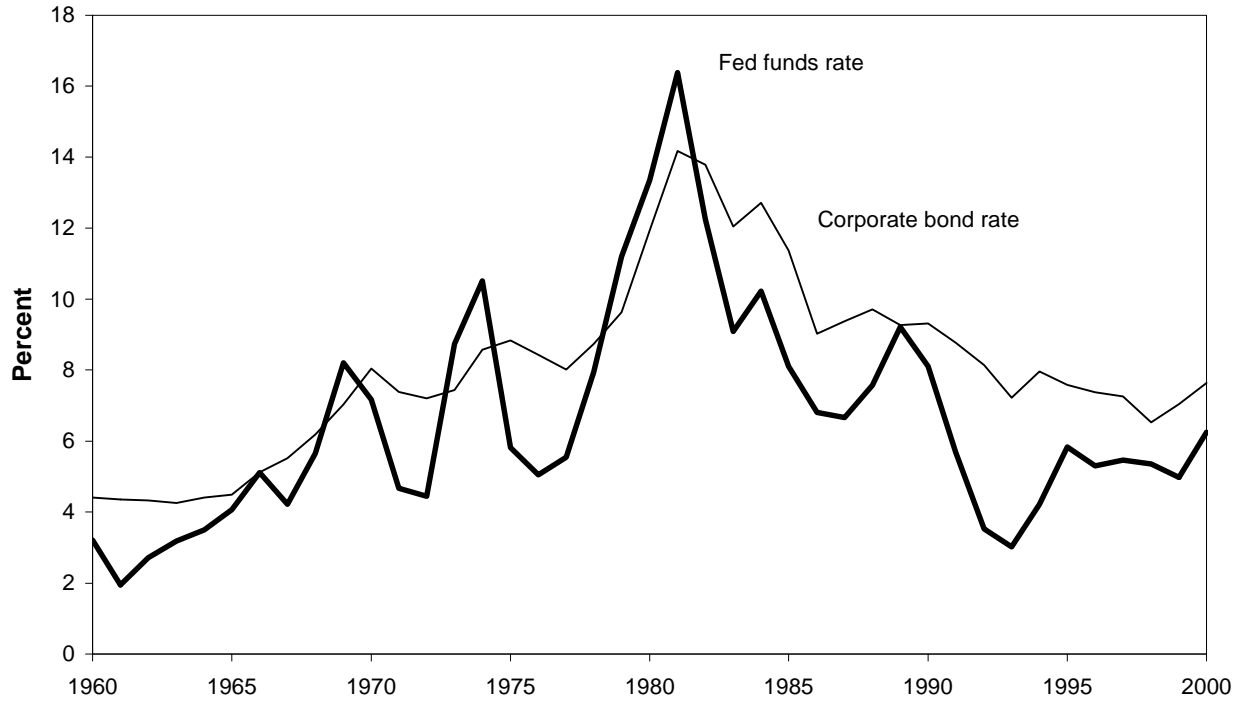
**Figure 1. Unemployment rate vs. inflation rate, 1960-2000**



**Figure 2. Unemployment rate vs. natural unemployment rate, 1960-2000**



**Figure 3. Fed funds rate vs. corporate bond rate, 1960-2000**



**Figure 4. Fiscal surplus vs. current account surplus**

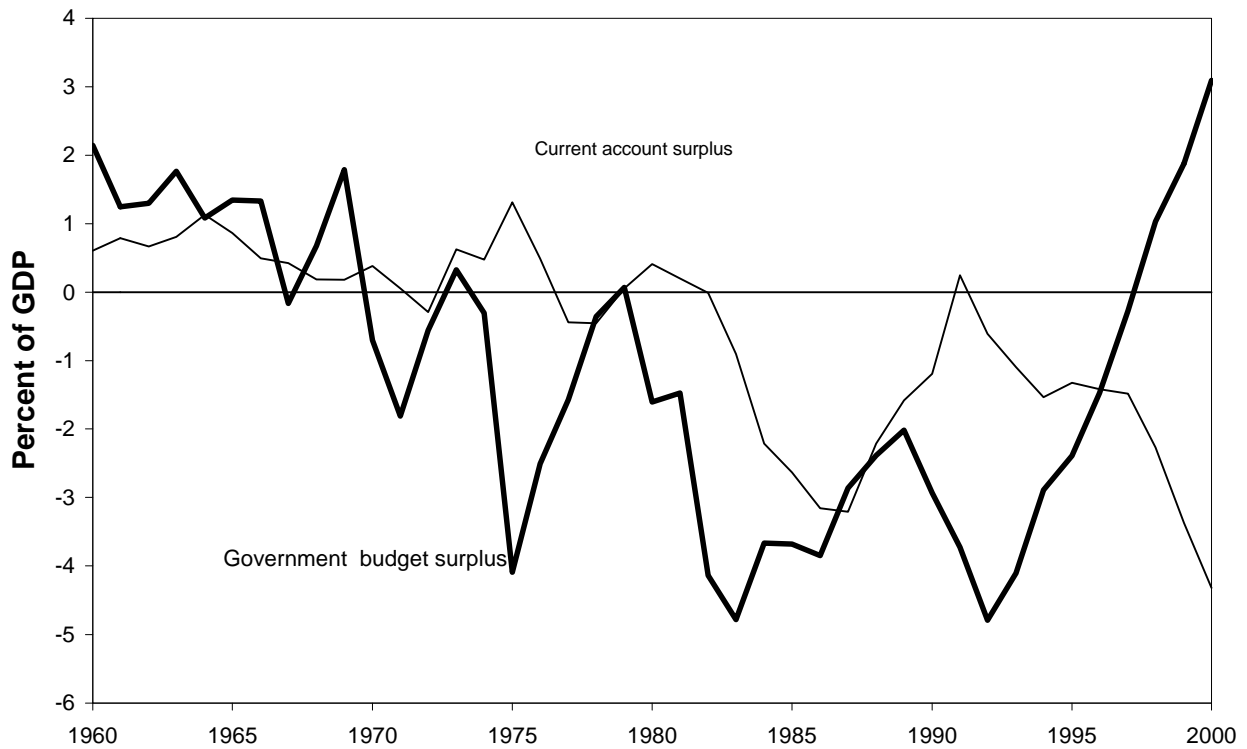


Figure 5. Components of Net Saving and Investment, 1960-1999

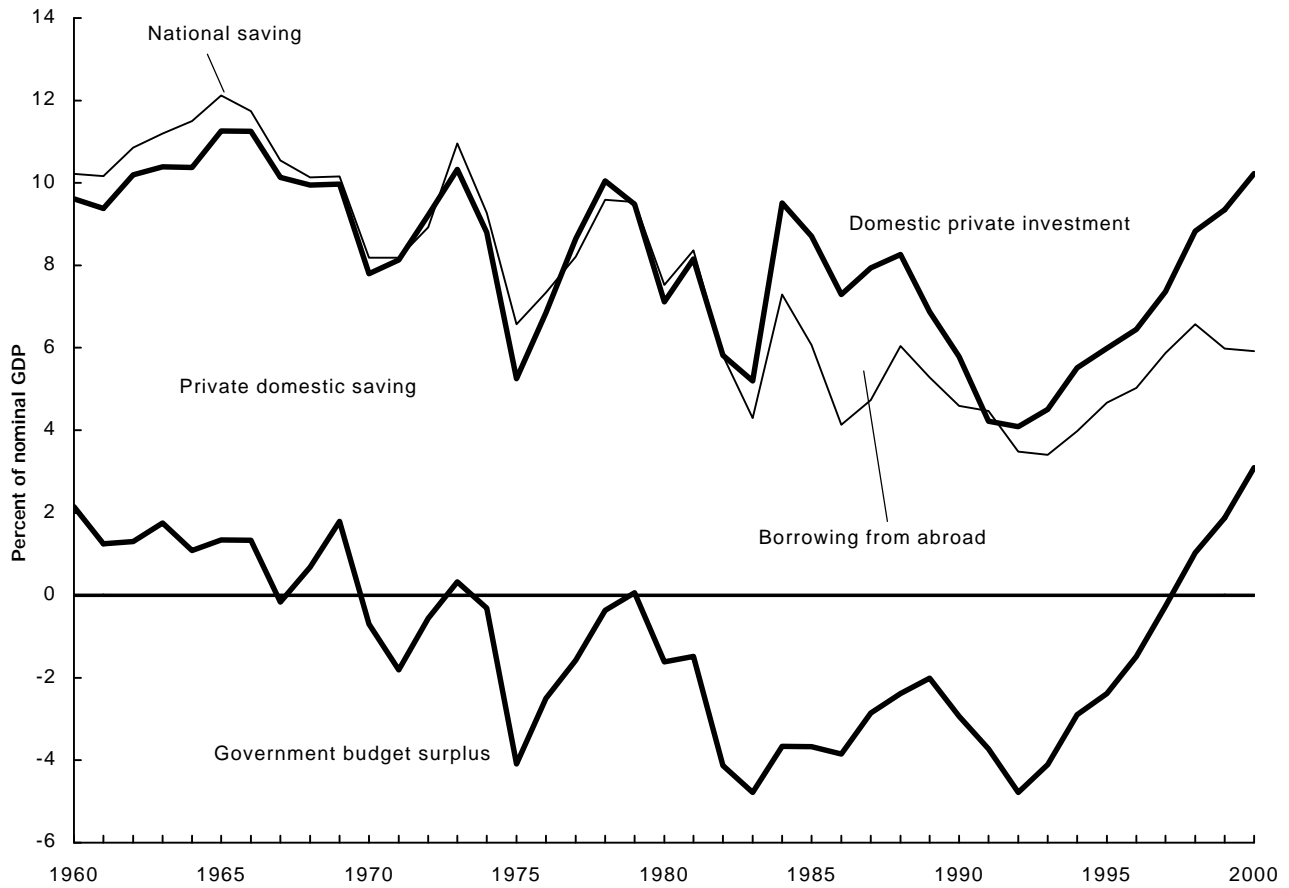
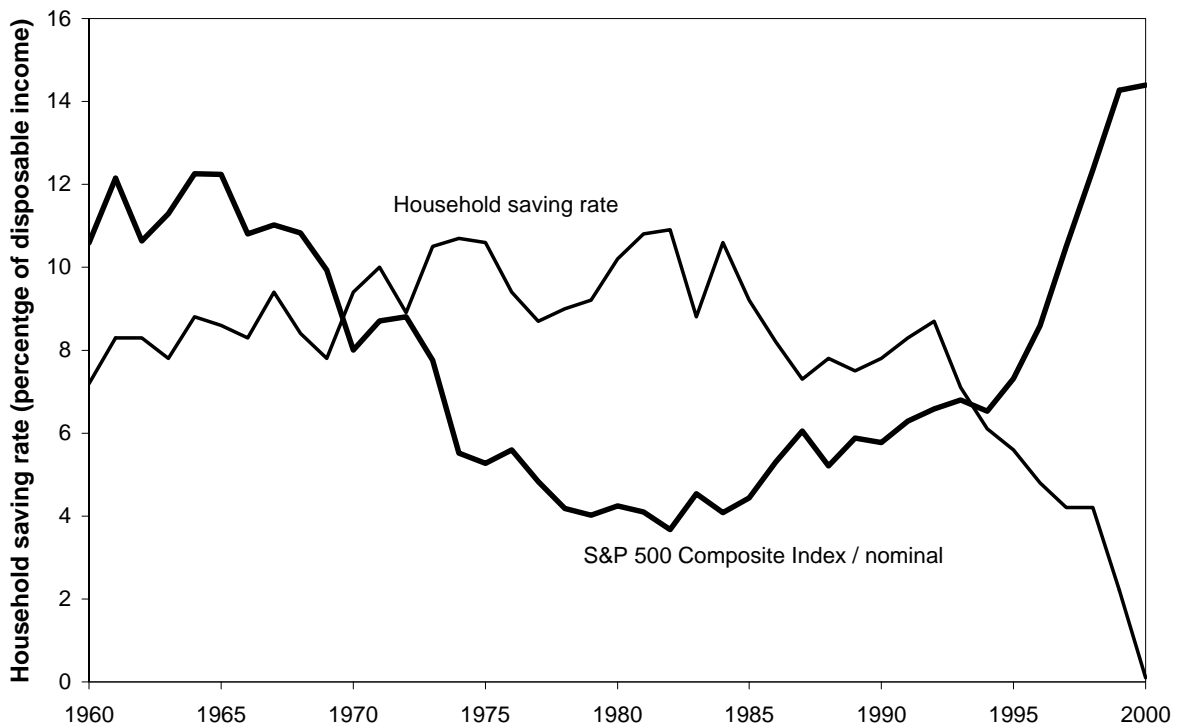
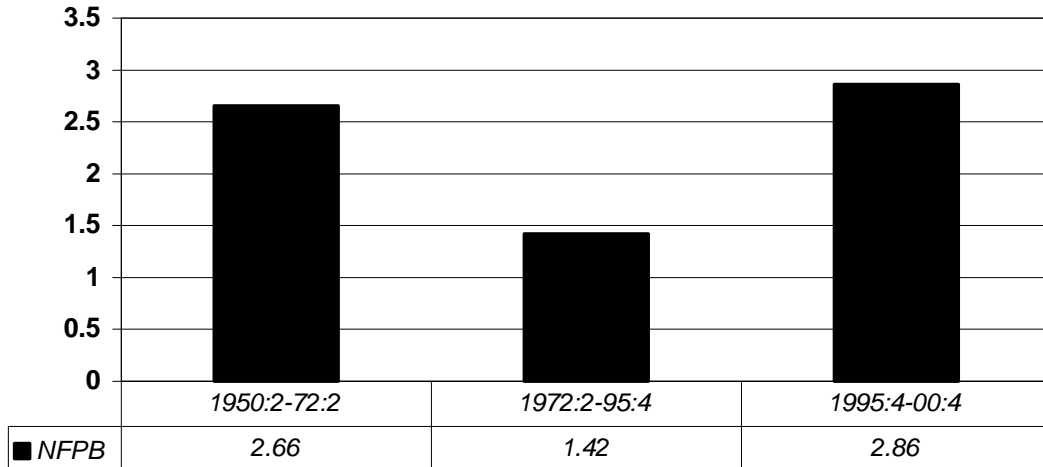


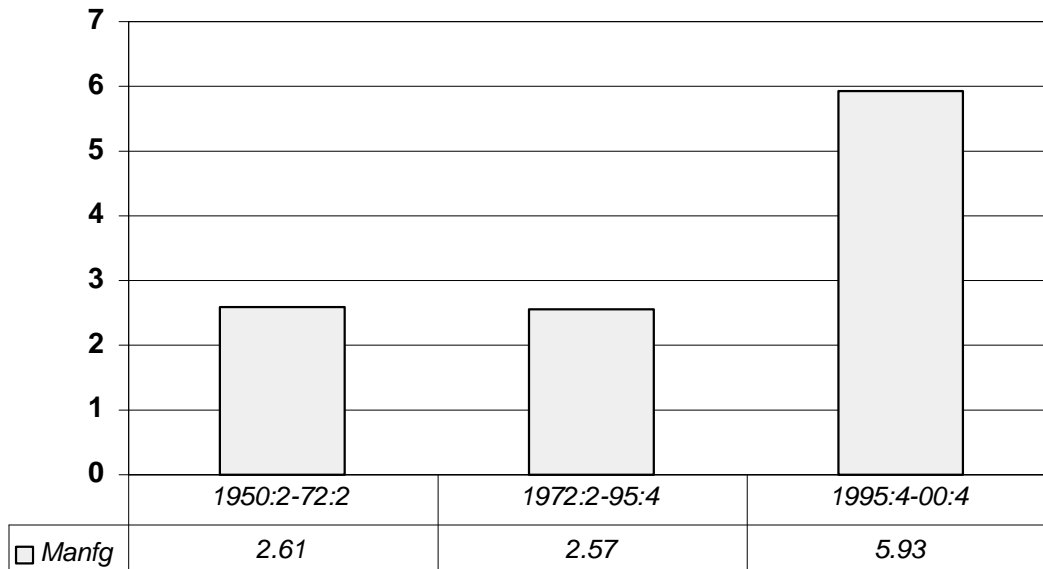
Figure 6. S&P 500/nominal GDP vs. household saving rate



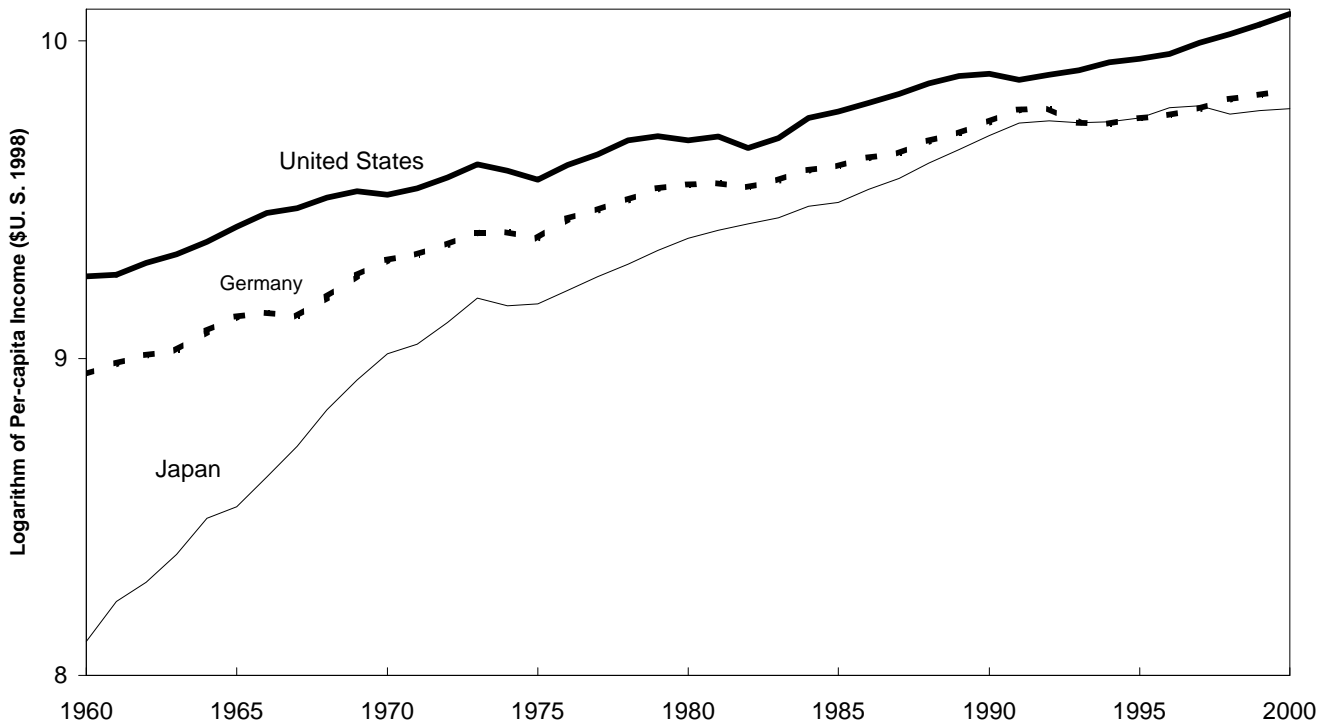
**Figure 7.a. Output per Hour, Nonfarm Private Business, Annual growth rates by interval**



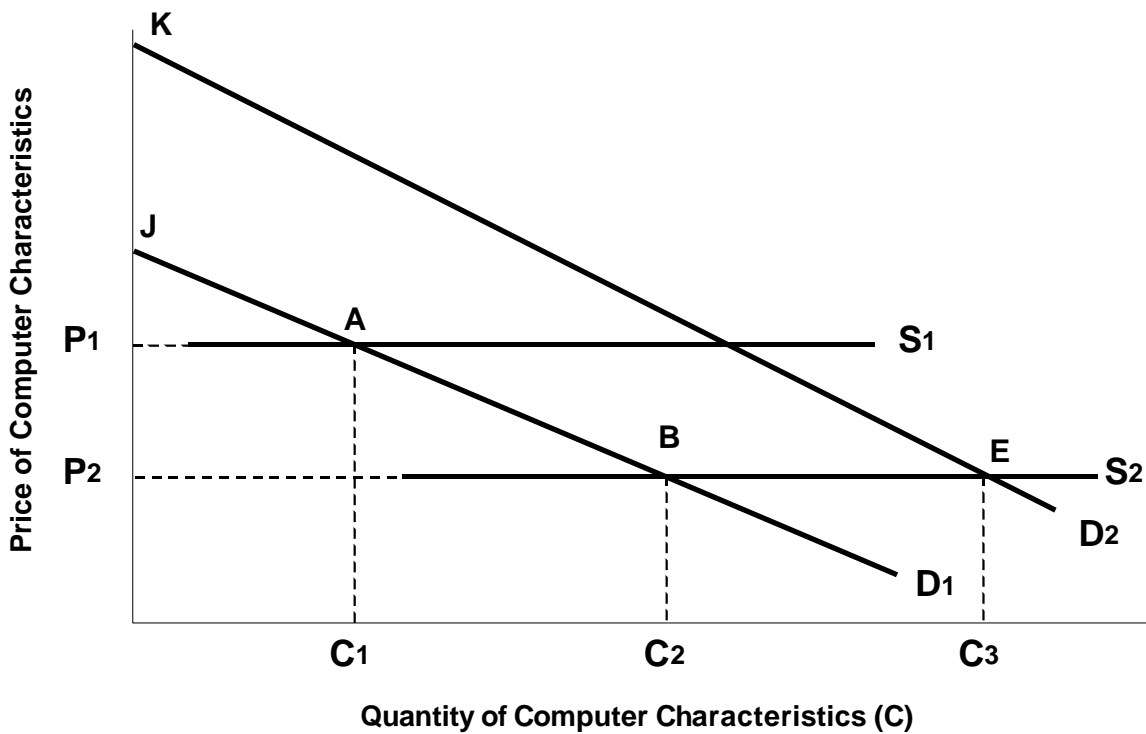
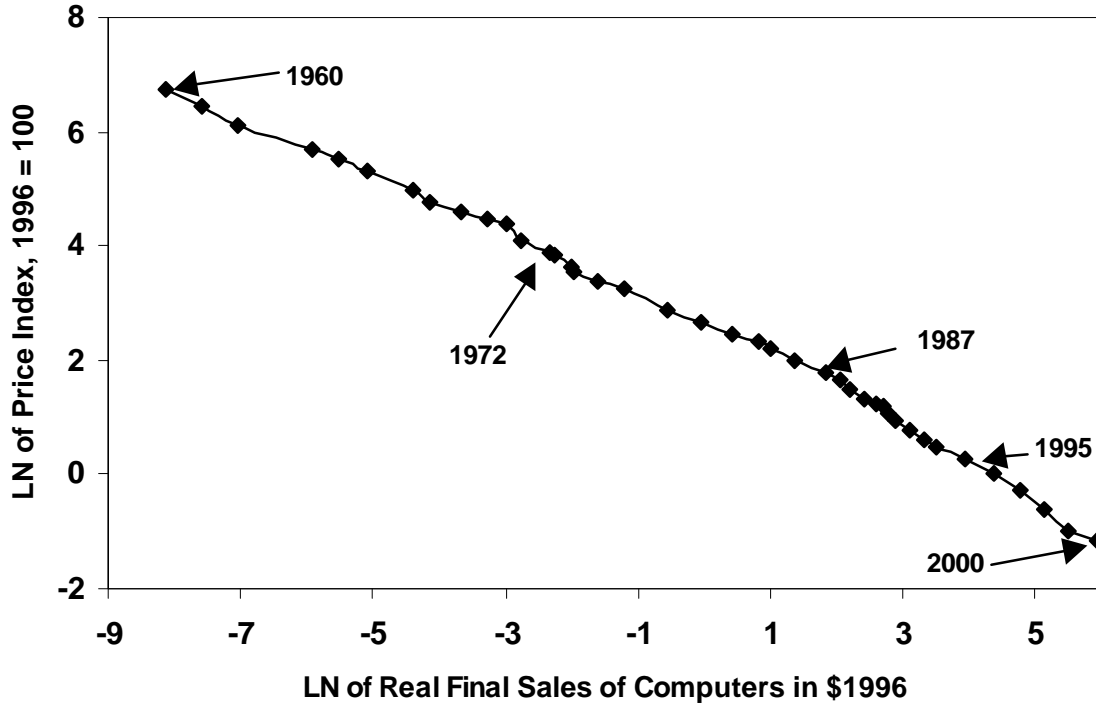
**Figure 7.b. Output per Hour, Manufacturing, Annual growth rates by interval**



**Figure 8. Per-capita Income for the Germany, Japan and the U.S., 1960-2000**



# Figure 9. The Price and Quantity of Computer Characteristics



**Figure 10. Final Sales of Computers and Peripherals,  
Four-quarter rate of Price Change and Nominal Share in  
Nonfarm Nonhousing Business GDP, 1987-2000**

