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FIVE PUZZLES IN THE BEHAVIOR OF PRODUCTIVITY, INVESTMENT, AND INNOVATION

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ABSTRACT

Productivity growth in the United States was considerably faster during 2000-2003 than in the boom years of 1995-2000. This ebullient productivity performance raises numerous questions about its interpretation and its implications for the future, and these are stated here in the form of five puzzles.

(1) Whatever happened to the cyclical effect? Skeptics were justified on the basis of data through the end of 1999 in their claim that part of the post-1995 productivity growth revival reflected the normal cyclical correlation between productivity and output growth. In contrast data through mid-2003 reveal only a negligible cyclical effect for 1995-99 but rather a temporary bubble in 2002-03. (2) Why did productivity growth accelerate after 2000 when the ICT investment boom was collapsing? The most persuasive argument points to unusually savage corporate cost-cutting and hidden intangible investments in the late 1990s that provided productivity benefits after 2000.

(3) The steady decline in the price of computer power implies steady technical progress, but then why did computers produce so little productivity growth before 1995 and so much afterwards? We draw an analogy to electricity, where miniaturization was the key step in making small electric motors practicable, and the internal combustion engine, where complementary investments, especially roads, were necessary to reap benefits. (4) What does the collapse of the investment boom imply about the future of innovation? First-rate inventions in the 1990s, notably the web and user-friendly business productivity software, are being followed by second-rate inventions in the current decade. (5) Finally, why did productivity growth slow down in Europe but accelerate in the U. S.? A consensus is emerging that U. S. institutions foster creative destruction and financial markets that welcome innovation, while Europe remains under the control of corporatist institutions that dampen competition and inhibit new entry. Further, Europe lacks a youth culture like that of the U. S. which fosters independence: U. S. teenagers work after school and college students must work to pay for much of their educational expense. There is a chasm of values across the Atlantic.

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Introduction

Understanding the interplay between innovation, technology, and productivity growth is the foundation for projecting the future economic growth rate of a country, a region, or the world. Because the United States has been at the frontier of productivity and living standards for at least the past century, it is understandable that so much of the productivity literature is U. S.-centric. Studies tend to divide the issues into those that involve accelerations and slowdowns in the rate of productivity growth in the United States, i.e., "at the frontier," and those that involve catching up and falling behind of other countries or regions relative to the United States. U. S.-centricity obviously overstates the role of the United States as a leader and innovator. There is plenty of innovation in the rest of the world, and U. S. manufacturers have been battered by losses of market share to higher quality and more innovative products from Japan, Europe, and elsewhere, especially in such industries as automobiles and machine tools. Further, the absolute level of productivity in several European countries now exceeds that of the U. S.[1] Nevertheless, this paper follows the U. S.-centric mold by placing disproportionate emphasis on U. S. developments and debates about their causes. Attention to Europe is secondary, mainly limited to the last section of the paper.

Almost four years after the end of the boom in the U. S. stock market and in Information and Communication Technology (ICT) investment, initial certainties about the causes of the post-1995 U. S. productivity growth revival are unraveling and puzzles deepen regarding not only its causes but also its durability. For numerous policy issues in the U. S. and other countries, long-term forecasts not just of productivity growth but of GDP growth are essential.

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1. McGuckin-van Ark (2004), Appendix Table 1.

For instance, long-run projections of government budget deficits and exhaustion dates for entitlement funds like U. S. Social Security depend heavily on projected growth rates of productivity and the population into the far future. Over a shorter horizon of one to two decades, growth forecasts are essential to inform government policy and corporate investment decisions and to predict the evolution of world trade, saving, and investment. As of early 2004, the U. S. productivity growth revival has lasted for more than eight years, and as it persists, it deserves an increasing weight relative to the dismal 1972-95 period of slow growth when making forecasts out into the distant future.

The Five Puzzles

It is difficult to understate the extent to which the recent behavior of U. S. productivity growth has surprised laymen and experts alike. Instead of fading after the economy's peak in mid-2000, U. S. nonfarm business productivity growth has actually accelerated from a 2.45 percent annual rate during 1995-2000 to a stunning 3.51 percent annual growth rate in the 14 quarters between 2000:Q2 and 2003:Q4. As U. S. productivity performance has become even stronger over the past three years, (at least) five puzzles have emerged regarding the revival, its causes, and the performance of the U. S. relative to the rest of the world.

1. Whatever happened to the cyclical effect? Is there any remaining support for the view that part of the post-1995 U. S. productivity revival contains a cyclical component, as I argued beginning in 1999 (Gordon, 2000)? In retrospect, was the initial decomposition of the revival as of 2000 between cyclical and trend elements justified, based on data available at that time? Can the early-recovery upsurge in productivity growth between late 2001 and mid-2003 be interpreted as a temporary phenomenon, as were temporary early-recovery upsurges in 1975-76, 1982-83, and 1991-92?

2. If the role of ICT investment has been exaggerated, what else caused the revival? U. S. productivity grew even more rapidly after the mid-2000 peak in ICT investment and the stock market than in 1995-2000 when ICT investment was strong. Yet the first round of academic research on the revival (Jorgenson-Stiroh 2000, Oliner-Sichel 2000) attributed most of the revival to the post-1995 explosion of ICT investment. Faster growth in ICT investment translated directly into a productivity benefit coming from the *production* of ICT hardware, and in addition a second, larger component came from the *use* of ICT capital across the economy, particularly in ICT-intensive industries. The continuation of relatively rapid productivity growth after the mid-2000 collapse of the ICT investment boom is puzzling and raises the question as to whether previous research attributed too large a causal role to ICT investment and, if so, what other factors could have contributed to the revival and its post-2000 continuation?

3. After fifty years of computers, what aspects of innovation caused productivity growth to take off? In previous writing (Gordon, 2000), I have argued that sustained rapid growth of U. S. productivity between World War I and the mid-1960s was propelled by a set of

"Great Inventions" at the end of the nineteenth century, of which the most important were electricity and the internal combustion engine. Simply inventing the computer did not deliver a similarly long and sustained era of rapid productivity growth; almost half of the fifty years since the first commercial application of the computer in 1954 experienced slow producitivity growth in the U. S. What were the key innovations that produced the post-1995 productivity revival in the U. S.? Have those key innovations already occurred, or can we expect a continuous pace of innovation over the several decades equal in importance to the late 1990s?

4. Does the slump in ICT investment tell us anything about the pace of innovation, or does a continuous pace of innovation suggest that ICT investment will soon return to the heady boom of the late 1990s? Like any magnitude in economics, the behavior of ICT investment can be summarized by changes in forces influencing supply and demand. The demand side depends on the steady arrival of innovations that create profitable investment opportunities. Without innovation, investment would have stopped centuries ago, as it would have involved "piling wooden ploughs on top of wooden ploughs" (Domar, 1961, p. 712). If innovation is the fundamental driver of the demand for investment, what does the rise and fall of ICT investment since 1995 tell us about the pace of innovation over the past decade, and what are the implications for the next decade?

5**. Why has Europe failed to experience a productivity growth revival?** Early interpreters of the post-1995 U. S. productivity growth revival immediately noted that, compared to the period 1990-95, Europe did not match the U. S. productivity growth acceleration but rather exhibited a growth slowdown. European productivity growth has remained slow in the years after 2000, while the U. S. has experienced yet another upsurge. Thus the puzzle deepens as to why Europe continues to slip behind, especially since Europeans use the same types of ICT hardware and software as in the U. S. This puzzle reinforces Puzzle #2, suggesting that there is some other source of U. S. advantage, but why should this have emerged only after 1995?

Plan of the Paper

The paper begins with Puzzle #1, discussing the cyclical behavior of productivity and the evolution of statistical trends estimated for U. S. productivity growth. Today's view of the underlying productivity growth trend in the 1995-1999 era is much more optimistic than from the vantage point of the year 2000, and this helps to explain why I could argue back then that a significant component of the post-1995 revival was "cyclical," whereas today's more optimistic trend for that period does not support a cyclical interpretation. Moreover, there remains a cyclical element in post-2000 productivity behavior, in the sense that in previous recoveries, an early recovery productivity growth "bubble" has been followed by below-trend growth during the subsequent two years, and there are reasons to suspect that ebullient U. S. productivity growth in 2002-03 could be followed by more modest (but still respectable gains) in 2004-05.

The treatment of Puzzle #2 also centers on data for the U. S., in this case the evolution over time of studies of the sources of the post-1995 productivity growth revival. How do such studies explain the continuation and acceleration of the productivity revival from the perspective of the post-2000 crash in ICT investment? Did such studies overstate the role of ICT investment in achieving the 1995-99 portion of the revival?

Examining Puzzle #3, we provide an overview of several major innovations that were important for productivity gains, including the "Great Inventions" of the late nineteenth century, their subsidiary and supplementary offshoots in the first half of the twentieth century, the initial impact of electronic computers, and finally the key aspects of the post-1995 "New Economy." Our key question is why the initial impact of computers on productivity growth petered out after 1970, and why an apparently continuous stream of innovations finally brought a productivity reward only after 1995.

Our treatment of Puzzle #4 argues that traditional decompositions of the sources of growth overstate the role of the quantity and quality of capital, and of improvements in the quality of labor, and understate the role of innovation in the process of economic growth. Innovation is necessary but not sufficient for investment to occur, and accelerations and decelerations of investment can be signals of changes in the pace of innovation.

Finally, Puzzle #5 leads us to examine the contrast in productivity behavior between the U. S. and Europe over various sub-intervals since 1990. Why did productivity growth slow down in Europe but accelerate in the U. S.?[2] To look for an answer, we provide an informal survey of explanations for the failure of Europe to join the U. S. in its productivity revival. We sift through a litany of complaints about European structural rigidity and overregulation in a search for convincing explanations of the differences. The final section summarizes and interrelates our proposed solutions to the five puzzles.

Puzzle #1: Whatever Happened to the Cyclical Effect?

Over the past five decades the growth rate of productivity in the U. S. has been highly volatile. Displayed in Figure 1 is the four-quarter rate of change of nonfarm private business productivity, displayed as the jagged black line. Despite the appearance of random zig-zags, we can pick out a few patterns in the behavior of the black line if we know the chronology of U. S. growth and business cycles.

Decomposing Cycle and Trend

The growth of productivity is not uniformly high in economic expansions and low in recessions. Instead, it tends to be relatively low in the last stages of an expansion, as firms optimistically hire too many workers just when the economy's growth is slowing. This "end-of-expansion" phenomenon was first identified in Gordon (1979) and then reaffirmed in subsequent data (Gordon 1993, 2003b). Examples go back to the 1950s and include 1968-69,

2. This acceleration has been made much stronger over the 2000-03 period by recent revisions to the U. S. data that are not yet reflected in most academic and journalistic comparisons across countries.

1973-74, 1978-80, and 1988-90. Periods of most rapid growth are in the quarters immediately following the business cycle trough, when output begins to grow but firms are still cutting costs and laying off workers. Examples of early-recovery productivity "bubbles" include 1975-76, 1982-83, and 1991-92. In these three cases there was a sharp slowdown in productivity growth after an initial four to six quarters of the "bubble."

To interpret productivity behavior since 1995, we add to the black line in Figure 1 two different trends for the rate of change, using the methodology of the Hodrick-Prescott (H-P) filter.[3] The extent of the post-1995 revival in trend differs, depending on how much data the H-P filter is allowed to "see". The solid smooth line is allowed to see data only through the end of 1999:Q4; it moves upward beginning in 1994 to reflect the sharp increase after 1995 in the average growth rate, but as of 1999:Q4 had increased only from 1.66 to 1.89 percent per annum. Allowing the trend estimation to be exposed to the full set of data through 2003:Q4 yields a much more rapid acceleration of the trend as far back as 1995. Clearly, the verdict on whether any of the post-1995 acceleration represented a cyclical effect depends on when that assessment was made and what data were available at the time. Both trend lines are identical prior to 1994 and agree that the productivity growth trend reached its maximum point in the early 1960s and then slowed to a trough of only around 1.0 percent per year in 1980, followed by a two-step

3. We use an H-P parameter of 6400 in preference to the standard 1600, which in our view causes trends to be too volatile and to adhere too closely to the actual values. Further discussion of detrending issues, and a comparison of the H-P and Kalman filters, is contained in Gordon (2003b, pp. 216-26).

revival, the first between 1980 and 1985, and the second after 1995.

Table 1 provides specific numbers for the actual and trend growth rates over alternative intervals. Between the 1950-72 and 1972-95 periods, the actual growth rate slowed from 2.60 to 1.53 percent per annum.[4] Stopping the clock at 1999:Q4, the actual growth rate for 1995:Q4-1999:Q4 had accelerated to 2.35 percent and the trend estimated at that point had accelerated to 1.81 percent, leaving a cyclical effect of 0.54 percent. The same exercise carried out by Gordon (2000, reproduced in the bottom line of Table 1) yielded somewhat higher numbers for actual and trend (because the data for that period have been revised downward since his paper was written) but almost exactly the same estimate of the cyclical effect, 0.50 percent.[5]

When the trend estimator is allowed to take into account all the data through 2003:Q4, the story changes substantially. Now the 1995-99 trend growth rate is 2.08 percent, not 1.81 percent, and the cyclical effect is down to 0.27 points. Further, the average actual growth rate after 1999 is up to 3.50 percent, of which 2.87 is estimated to represent trend growth and a remaining 0.63 represents a renewed cyclical effect.

Interpreting the Productivity Growth "Bubbles"

In view of the volatile zig-zags of productivity growth evident over the postwar history

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4. All the numbers in Table 1 are based on BLS data as of March, 2004, and reflect the revisions to the national accounts and hours data introduced in August and December, 2003.

5. Gordon (2000) estimated the trend by an alternative technique that had been used in Gordon (1993), which was to find the 1995-99 productivity trend that provided the best fit in a regression of changes in detrended hours on changes in detrended output, allowing for lags in both hours and output..

displayed in Figure 1, how much of the robust post-1999 behavior is likely to persist? The HP trend had reached 3.04 percent by late 2003 -- will it level off, accelerate further, or decelerate as happened after the peak of slightly above 3.00 percent was reached in 1964? One way to examine this question is to liken the peak growth in 2002-03 to three earlier "bubble" periods in the first few quarters of recoveries from recession troughs, namely 1975-76, 1982-83, and 1991-92.

We can use the regression specification developed in Gordon (1993, 2003b) to divide up productivity growth into three components, (1) a portion explained by the lag of hours adjustment behind output changes, (2) the "end-of-expansion" (EOE) mechanism, and (3) an unexplained residual. The decomposition is shown in Table 2. In the 1975-76 episode the sharp downward and upward zigzag of output followed by hours in that sharp recession explained about half of the temporary spike of productivity growth, and the EOE more than explains the rest. In 1982-83 most of the explanation is carried by the EOE effect, with only a small contribution of lagged adjustment. In the two mild recessions of 1990-91 and 2001 there was only a mild drop in output, and so lagged adjustment explains nothing, the EOE explanation is partial, and particularly in 2001-2002 most the bubble remains unexplained.

For our purposes in trying to guesstimate what the productivity trend will look like in the future, an important precedent is that over the eight quarters following the bubble, productivity growth was slower than trend by an average of -0.27 percentage points over the three previous episodes, and the deceleration from the four-quarter bubble period to the eight-quarter post-bubble period was an average of -3.07 percentage points. Applying this average reaction to the current period would imply that actual productivity growth between 2002:Q4 and 2004:Q4 would fall 0.27 points short of its 3.04 percent trend, averaging 2.77 percent over this interval. However, the first five quarters of this interval have already occurred and the average annual growth rate so far is not 2.77 percent but rather 4.62 percent, much faster than the prediction based on past post-bubble episodes and also much faster than the trend estimated for late 2003.

The extraordinary explosion of productivity growth in 2002-03 goes far beyond any precedent based on normal cyclical behavior. Below we discuss two possible explanations, the role of unmeasured intangible capital, and the unusual trajectory of profits and the stock market which led to savage cost-cutting in the years after mid-2000. The counterpart of the productivity growth explosion is a "jobless recovery" much more extreme than in 1991-92; this has become a central issue in the U. S. Presidential election campaign of 2004.

Our verdict on Puzzle #1 is that, based on data in late 1999, skeptics were correct to attribute part of the post-1995 productivity growth acceleration to a temporary cyclical effect. But the data that emerged in 2000-03 provide a much more optimistic measure of the acceleration in the growth trend and suggest that little of the late 1990s upsurge was cyclical. However, based on data up to the end of 2003, it appears that a substantial part of explosive productivity growth of 2002-03 is unsustainable, even though the trend itself has accelerated to slightly above 3 percent, thus matching the previous postwar peak reached in 1964. In 2002-03, the "early recovery productivity bubble" lasted substantially longer than in previous early recovery episodes, and the counterpart of a "jobless recovery" also lasted longer. The U. S. economy is on track to achieving a rate of productivity growth over the decade 1995-2005 of almost three percent per year, raising deep questions about why this has occurred and why these causes have not been equally relevant in Europe. .Below we return to the explanation of this unusual productivity cycle.

Puzzle #2: If the Role of ICT Investment has been Exaggerated, What Else Caused the Revival?

As we have seen, productivity growth was substantially more rapid after mid-2000 than during the initial revival period of 1995-2000. However, the most prominent studies by Jorgenson and Stiroh (2000) and Oliner and Sichel (2000) attributed a large fraction of the revival to the *production* and *use* of ICT equipment and software. In the case of Oliner and Sichel, the analysis included not only ICT capital, including software, but also the semiconductors that powered the hardware. This leads us to Puzzle #2, the fact that productivity growth proceeded to a second stage of acceleration during 2000-2003 just as the ICT investment boom collapsed.

Data on real investment in computers and other products with rapid relative price changes become increasingly more misleading as time extends past the base year in the national income accounts, currently 1996 in the U. S. To avoid potential errors of interpretation, the correct measure of the importance of ICT investment is the *nominal* share of that particular type of investment in *nominal* GDP. For computer hardware itself, that share averaged 0.96 percent in 1997-2000 but then crashed to 0.71 percent in 2002 and by 2003:Q2 had recovered only to 0.77 percent. A more comprehensive measure that includes not just computer hardware but also software and "other" (mainly communications) equipment registered an average GDP share of 4.23 percent in 1997-2000, reaching 4.55 percent in the year 2000, and then fell to 3.83 percent in 2002 before recovering to 3.94 percent in 2003:Q2.

The Oliner-Sichel Decomposition

The most influential research supporting a large role for ICT investment in the post-1995 productivity growth revival appears in a series of papers by Stephen Oliner and Daniel Sichel, hereafter O-S (2000, 2002). Their approach, presented in Table 3, has attracted wide attention because of the clarity with which they distinguish between the role of capital deepening of ICT capital (line 3), that is, the benefits of rapid ICT investment to the *users* of ICT capital, from the separate role of the *production* of ICT capital in raising the growth rate of multifactor productivity for the economy as a whole (line 10). It is easy to follow the evolution of the O-S results as new data emerge, because they are always presented in the same format, and because the same initial time period (growth rates from 1973 to 1995) is compared with the revival period of 1995 to the latest year for which data are available.

Table 3 compares the initial O-S (2000) decomposition with their latest unpublished results which extend the findings to an end-date of 2002.[6] The table displays the growth rate of labor productivity in line 1 and then in lines 2 and 8 subtracts the contributions of capital deepening and improvements in labor quality (i.e., education) to arrive at the growth rate of multifactor productivity (MFP). The capital deepening component is further subdivided into ICT and other capital and into three types of ICT capital (lines 4-6). The resulting MFP growth rate is then decomposed into the role of the *production* of ICT capital and all other contributions to MFP growth (lines 10-11).

In Table 3 we add two additional lines to the standard O-S decomposition. The two types of ICT capital contribution, capital deepening (line 3) and the MFP effect (line 10) can be added together, as in line 12. Then the total ICT contribution in line 12 can be divided by the growth rate of labor productivity from line 3 to yield the total contribution of ICT capital to productivity growth and to the productivity revival, as shown in line 13. Table 3 shows three different decompositions of the post-1995 productivity growth revival, each shown in boldface and italic type. The first with data through 1999 is taken from the initial O-S paper, while the second uses the latest data for the same period. Data revisions reduce the overall productivity revival in line 3 while leaving the ICT contribution intact, and this boosts the contribution of

6. There have been intervening analyses of data ending in 2000 and 2001 (see Oliner-Sichel 2002); these are omitted to simplify the table and because the most recent results are of greatest interest.

ICT capital to the 1995-99 revival from 81 to 98 percent (line 13).

When the end-point of the data is extended from 1999 to 2002, the revival in the growth rate of labor productivity (line 3) increases from 0.96 to 1.20 percentage points while the contribution of ICT capital (line 12) shows surprisingly little response to the decline in ICT investment discussed above. As a result, the contribution of ICT capital declines from 98 percent in the period ending in 1999 to 76 percent in the period ending in 2002.[7] The spurt in productivity growth from 1999 to 2002 is more than explained by capital-deepening in "other capital" (line 7) and more rapid MFP growth contributed by sectors of the economy other than ICT and semiconductor capital. The puzzling absence of a decline in the ICT contribution as well as the upsurge in "other" capital deepening both can be traced to the same cause, the rapid decline in hours of labor input in 2001-2002. Since all the capital deepening terms in lines 2-7 represent the change in a capital-labor ratio times an income share of that type of capital, the apparent resilience of the ICT role disguises the fact that the ICT contribution by itself fell by half between 2000 and 2002, but this is dampened by the rapid decline in labor input.

Delay and Intangible ("Hidden") Capital

Drawing back from the details of Table 3, we can take a broader view of the claim that,

7. Data revisions released on August 7 would further reduce the ICT share of the 1995-2002 revival from the 76 percent figure shown in Table 3 to 67 percent, allowing only for the revisions in labor productivity and assuming no revisions for any other figure in the final column of Table 3. Current productivity data may exaggerate the 2002-2003 productivity performance, as they reflect extensive downward revisions in aggregate hours of labor input but will not until December, 2003, reflect the most important set of benchmark revisions in the national income accounts (which contribute output, investment, and capital data) to occur since 1999.

at least through 1999, virtually all of the productivity growth revival can be attributed to the production and use of ICT capital. This finding seems compatible with numerous studies, especially Triplett-Bosworth (2002) and Nordhaus (2002c), which pinpoint wholesale and retail trade and securities trading as the industries outside of ICT manufacturing where the productivity growth revival is most evident. The largest single contribution to the revival in their work is capital-deepening in ICT capital (Table 3, line 3), and this is precisely the capital that has been used so effectively in trade and securities trading.

Nevertheless, several questions may be raised about the implication of Table 3 that the post-1995 productivity revival, at least through 1999, resulted entirely from the production and use of ICT equipment.[8] First, the Oliner-Sichel technique requires that the full productivity payoff from the use of computers occurs at the exact moment that the computer is produced.[9] Leaving aside any delay between production and installation, the computer produces its ultimate productivity benefit on the first day of use. Numerous observers, led by David (1990), argue instead that there is a substantial time delay in reorganizing business practices to take advantage of new hardware and software. If there is a substantial delay in the real world that is not taken into account by the Oliner-Sichel method, then they would exaggerate the

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8. One of the interim versions of the O-S decomposition went through an end-point of 2001 and concluded that ICT capital *overexplains* the revival dated as 1995-2001 (see Sichel's discussion of Nordhaus, 2002c).

9. Recall that the GDP statistics on which they rely measure output by production, and treat any unsold goods as inventory accumulation, a part of GDP.

contribution of ICT capital-deepening to the post-1995 revival during the years of peak ICT investment. Then, in the period 2001-03 when ICT investment has declined, they would understate the left-over benefits from previous ICT investment.

David's (1990) "delay" hypothesis was based on a very general analogy between the invention of electricity and computers. We will return to this analogy in more detail below when we discuss Puzzle #3 about the fundamentals of New Economy innovation. In this section we consider a more specific and focussed argument by Yang and Brynjolfsson, hereafter Y-B (2001), that the productivity revival in the late 1990s was fundamentally mismeasured, due to the exclusion of massive amounts of "intangible" or "hidden" capital from the investment and capital data in the national accounts, and hence from the growth accounting exercises such as that of O-S as summarized in Table 3.

Y-B begin by treating computer hardware as the tip of the ICT iceberg, concealing a large quantity of complementary capital investment, perhaps in their words as much as 10 dollars of "complementary intangible capital (including software and data), new business processes, and human capital." The key distinction is between the portion of the total investment that is included as investment in the national accounts, and the remaining intangible portion that is "hidden" as a business expense rather than treated as investment. However, the Y-B 10-to-1 ratio greatly exaggerates the hidden component. We have already seen that in 2002 investment in computers and peripherals was just 0.71 percent of GDP, in contrast to investment in all ICT capital, including software, of 3.83 percent of GDP, or more than five times as much. Thus a better rule of thumb might be that each dollar of investment in computer hardware (including peripherals) generates four additional dollars of measured ICT investment in software and communications equipment, and as much as five additional hidden dollars of business process reorganization and investment in human capital, i.e., retraining.

Picking up a theme discussed below in regard to Puzzle #3, we regard investment in computer hardware as automatically generating not only investment in software but also investment in communication equipment, and in fact that is why we use the abbreviation "ICT" in preference to "IT" throughout this paper. The essence of the New Economy was the marriage of computer and communications hardware with software; the computer hardware and communications hardware interacted in so many ways that it is impossible to separate them and claim that one is at the tip of the iceberg while the other remains under water. The invention of the World Wide Web (WWW) spurred not just a massive wave of computer and peripheral purchases, along with the development of Windows 95 and 98 that incorporated integrated web browsers, but also an enormous investment in communications hardware, including not just fibre-optic cable but also everything from mundane plugs to complex electronic switching networks. Working in the opposite direction, the rapid spread of mobile phones required heavy investment in computer hardware to operate and manage the mobile phone networks. The entire computer and communications hardware component of investment, as well as software, is a portion of the iceberg that is fully visible and above water.

Whatever the ratio of hidden intangible capital, more likely 1-to-1 than 9-to-1, the implications of the Y-B argument become clear. The economy's production function for final goods depends on measured labor, measured capital input, and hidden intangible capital input. In a steady state, when new investment in open and hidden capital is balanced by depreciation, and human capital and retraining functions are at a normal level required to replace workers who quit or retire, then hidden inputs and hidden outputs offset each other, and there is no mismeasurement of productivity.

But when visible ICT is growing rapidly as during 1995-2000, then complementary hidden investments are growing rapidly as well, and the unmeasured output (the present value of future benefits from business process reorganization, human capital improvements, and retraining) exceed unmeasured inputs. Yet much of this intangible capital is being created by measured labor inputs (programmers, consultants, trainers) that appear in the denominator of productivity while their output is not counted in the numerator. Thus during 1995-2000 the "true" revival of productivity growth, including the hidden output in additional to measured output, was substantially greater than the measured revival of productivity growth which was held down both by the failure to count intangible investment and also by the counting of a temporary upsurge in labor input devoted to creating intangible hidden capital.

The period 2000-2003 has been marked by a sharp downturn in ICT investment, particularly in computer hardware but also in software and communications equipment, and a rapid decline in employment. Output can grow despite a continuing decline in labor hours, because the benefits of the previous hidden investment in improved business processes and better trained employees are transmitted to production, while the workers that produced the hidden output in the late 1990s (programmers, consultants, trainers) have been laid off and are walking the streets. In a sense the U. S. economy of 2000-2003 has been getting a "free ride" from the 1995-2000 wave of investment in hidden capital.

The Y-B analysis seems convincing as at least a partial explanation of why U. S. productivity growth has been so healthy during a period of relatively low *measured* ICT investment. However, its starting point is that an imbalance of measured and hidden investment is inherently temporary and depends on an acceleration or deceleration in visible, measured investment such as that which occurred on the up side during 1995-2000 and on the down side during 2000-2003. The implication is that part of the ebullient productivity performance of 2000-2003 was based on the "free ride" and is inherently temporary. This argument is *in addition* to the historical precedent of an early-recovery productivity growth "bubble" such as occurred in 2001-2002, which suggests that average measured productivity growth during 2000-2003 contains a cyclical component.

At least one obvious question is raised by the Y-B analysis, and this is why intangible capital did not produce a productivity growth upsurge during previous periods when the share of spending on computer hardware was growing rapidly, particularly 1972-87, the interval that led Robert Solow to utter his famous quip that later became known as the Solow "computer paradox," that "we see the computer age everywhere except in the productivity statistics". One possible answer is that the 1972-87 increase in the share of computer spending in GDP was slow and gradual, while the post-1995 upsurge was sudden and hence created a greater imbalance between measured and unmeasured ICT investment. A second possibility is that the nature of ICT innovation in the 1990s was more disruptive and required a more substantial investment in intangible capital than did earlier waves of computer innovation. We turn to this possibility in the next section.

The Y-B intangible capital hypothesis is not the only explanation of the extraordinary behavior of U. S. productivity growth in the 2000-03 period, which as we have seen goes well beyond the usual early-recovery bubble phenomenon. Another explanation centers on the unusual behavior of profits in the late-1990s boom and subsequent stock market collapse, leading to unusually savage cost-cutting in 2000-03, with the resulting "jobless" recovery and productivity growth explosion.

Profits are related to productivity through the income shares of labor and capital. By definition labor''s share is equal to real compensation per hour divided by output per hour. If increases in compensation lag behind productivity in the early phases of a cyclical expansion, then labor''s share will decline and capital''s share will rise, and the rate of return on capital will rise even faster to the extent that the rising utilization of capital causes an increase in capital productivity. The cyclical expansion of the 1990s exhibited typical behavior of corporate profits as measured in the NIPA, which registered a near-doubling of nominal profits between 1992 and 1997 followed by a decline in nominal profits between mid-1997 and early 2000, little further decline into 2001, and then a recovery in 2002 and early 2003 back to the 1997 nominal peak and beyond.

Nordhaus (2002b) contrasts the behavior of NIPA profits with that of S&P reported profits, which show a very different timing pattern, growing by 70 percent between early 1998 and early 2000, and then declining by more than half between early 2000 and early 2001. He attributes a substantial role in this "most unusual pattern" to a wide variety of shady accounting tricks to which corporations turned as they desperately attempted to pump up reported profits during 1998-2000 in an environment in which true profits were declining. In Nordhaus' words, these tricks led to "the enrichment of the few and depleted pension plans of the many." A further unusual aspect of 2001-02 was the extremely low ratio of S&P reported earnings to S&P operating earnings, primarily due to one-time charges that firms take to correct for previous business or accounting mistakes. Overall, Nordhaus estimated that reported S&P earnings for 2001 were held down by about 30 percent by a combination of normal cyclical and extraordinary accounting impacts.

The unusual trajectory of S&P reported profits in 1998-2001 placed unusual pressure on corporate managers to cut costs and reduce employment. During the 1990s corporate compensation had shifted to substantial reliance on stock options, leading both to the temptation to engage in accounting tricks during 1998-2000 to maintain the momentum of earnings growth, and then sheer desperation to cut costs in response to the post-2000 collapse in reported S&P earnings and in the stock market. The stock market collapse had an independent impact on the pressure for corporate cost-cutting, beyond its effect on the stock-option portion of executive compensation, by shifting many corporate-sponsored defined benefit pension plans from overfunded to underfunded status.

A plausible interpretation of the unusual upsurge of productivity growth in 2002-03 is that it was the counterpart of an unusual degree of pressure for corporate cost-cutting, which in turn was caused by the role of accounting scandals and corporate write-offs that led to the unusual trajectory of reported S&P profits relative to NIPA profits. The unusual nature of corporate cost cutting was widely recognized:

> "The mildness of the recession masked a ferocious corporate-profits crunch that has many chief executives still slashing jobs and other costs. . . . Many CEOs were so traumatized by last year''s profits debacle that they are paring costs rather than planning plant expansions"" (Hilsenrath, 2002).

The chain of causation from the profits "debacle" to the 2002-03 productivity surge seems plausible as the leading explanation of the unusual productivity paper documented in previous sections. But it raises a central question — how were corporate managers able to maintain output growth while cutting costs so savagely? Why didn''t massive layoffs cause output to fall, as would have occurred if productivity growth had stagnated? This brings us to the central role of ICT investment in the post-1995 productivity growth revival and to the puzzle that productivity growth surged after 2000 as ICT investment growth was collapsing along with corporate profits and the stock market.

Puzzle #3. What Aspects of Innovation Caused Productivity Growth to Take Off?

A fundamental puzzle in the history of computers is that innovation proceeded apace throughout the 50 years after the introduction of the first commerical computer in 1951, but productivity gains in the overall economy were slow during most of the 1972-95 period when some of the most important innovations occurred. Nordhaus (2002a) has documented that the rate of price decline of one standardized unit of computing power was roughly constant from the late 1940s to the present time at an annual rate of 40 to 50 percent per year, after barely declining at all from the first punch-card machines of the 1890s to the introduction of the electronic computer in the late 1940s. Thus the technology that allowed the price of one unit of computing power to decline at such a steady pace must itself have improved steadily. Why was the economy's response in terms of productivity growth so slow between 1972 and 1995, and so much more rapid after 1995? How long will the rapid response continue, or is the economy doomed to return, starting tomorrow or in several years, to an era of slow productivity growth?

The Early Years of Computers compared to the Great Inventions

I have previously compared, somewhat unfavorably, the invention and development of the electronic computer with that of the "Great Inventions", of which the two most important were the heroic twin inventions of the late nineteenth century, electricity and the internal combustion engine. David's (1990) "delay" hypothesis provided the first suggestion that it was useful to compare the early years after the invention of electricity to the early years after the invention of the electronic computer. We may look for analogies also with the early years after the invention of the internal combustion engine.

Electricity dates from the simultaneous invention of the electric light bulb in 1879 by Thomas A. Edison in the U. S. and by Joseph W. Swan in England, and the first power station in 1882. As shown by Nordhaus (1997), electricity drastically reduced the price of a lumen of light. Electric motors, after a developmental period of several decades, revolutionized manufacturing by decentralizing the source of power and making possible flexible and portable tools and machines. After a somewhat longer lag, electric motors embodied in consumer appliances eliminated the greatest source of drudgery of all, manual laundry; through refrigeration virtually eliminated food spoilage; and through air conditioning made summers enjoyable and opened the southern United States for modern economic development. In fact, it has been said that the most important economic development in Asia in the twentieth century was the invention of air conditioning.[10]

When comparing the importance of electricity and electronic computers, the initial and most obvious remark is that computers are one more subsidiary invention made possible by electricity and could not exist without it. More interesting is the role of size in the evolution of both electricity and computers. The upsurge in U. S. manufacturing productivity in the 1920s has been attributed to success, after a long delay, in making electric motors small and reliable enough to be stationed at each workplace in the factory and to replace the clumsy system of belts linking a large central power source to the individual work stations (David-Wright, 1999). In turn, the miniaturization of the electric motor made possible consumer appliances and air conditioning, subsidiary inventions that were not possible in the early days (say, 1880-1910) of electric power generation.

The history of the electronic computer in similar fashion reflects the role of miniaturization. Early electronic computers were massive and required separate air conditioned rooms or even separate buildings.[11] The 1950-80 period was characterized by the

10. This remark was made in the discussant remarks of Tacho Bark of Seoul National University at the International Conference on Growth Engines of Korea, Seoul, July 24, 2003.

11. The first electronic computer, the ENIAC developed in the late 1940s, had only a tiny fraction of the computing power of a contemporary laptop but was 100 feet long, ten feet high, three feet wide, and contained about 18,000 vacuum tubes. It was "programmed" by setting thousands of switches (Gordon, 1990, p. 191). For the early history of computing prior to 1950, see Nordhaus (2002a) and the sources provided there.

gradual shrinkage of the mainframe computer and the gradual transition of its input-output interface from punch cards to "dumb" terminals that had no separate computational capability. The earliest uses of electronic computers were similar to those of the early punch-card sorting machines dating back to the 1890s, namely to count the U. S. decennial census. Early commercial uses in the 1960s and 1970s were the production of telephone and utility bills, bank statements, and once the dumb terminal was available, prototypes of the modern airline reservation systems. Computers should have yielded major improvements in productivity by eliminating many rows of clerks sitting at desks with electro-mechanical calculators, and doubtless they did. But, as originally pointed out by Oliner and Sichel (1994) and Sichel (1997), these productivity gains barely showed above the surface in an economy where, in the 1960s, computer investment was barely 0.2 percent of GDP.

The invention of the personal computer in the early 1980s is analogous to the spread of small electric motors installed in machine tools and other factory equipment in the 1920s. Now individually controllable computational capability was available at every desk. While mainframes were still necessary for large assembly-line functions like bills, bank statements, and airline reservations systems, the personal computer allowed the introduction of word processing and spreadsheets. Economy-wide productivity should have surged in the 1980s as personal computers made it possible for firms to economize on secretaries who had previously been engaged in repetitive typing of legal briefs and contracts. Professors soon found that it was faster to word process their own papers from scratch than to follow the tedious previous process of endless rounds of revising drafts typed by a secretary. Indeed, one can see a faint glimmering of an early revival in productivity growth in the 1981-85 period in Figure 1 above.

Sharing the title with electricity for the most important invention that had its main diffusion in the twentieth century is the internal combustion engine, which made possible personal autos, motor transport, and air transport.[12] The early years of the internal combustion engine were also characterized by a David-type delay, but this did not involve miniaturization. Initially automobiles were quirky and unreliable, and while autos soon became capable of traveling at much faster speeds than horses, the roads required for such speeds did not exist. Only in the 1920s did automobiles become sufficiently pervasive to spell the doom of inter-urban street railways. Only in the 1950s did the full set of the automobile's complementary inventions, including supermarkets, suburbs, and superhighways, finally emerge. Similarly more than twenty years elapsed after the Wright Brothers' first flight before the start of the commercial aviation industry in the late 1920s, and ten more years intervened before the development of the DC-3, the workhorse commercial aircraft that made possible the modern airline industry beginning in the late 1930s.

The analogy of the internal combustion engine provides the key to understanding why

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12. The first internal combustion engine operating on modern principles is attributed to Julius Hock in 1870 and the first four-cycle engine to Nikolaus Otto in 1877. The first high-speed engine was built by Gottlieb Daimler in 1883 and the first three-wheeled automobile by Karl Benz in 1885. See Bunch and Hellemans (1993), pp. 268-93.

the productivity payoff of the personal computer waited until the mid-1990s. Just as complementary investments in roads and suburbs were necessary to provide the full benefits of motorcars and motor transport, so complementary innovations in software and communication technology were necessary to provide the full potential benefits of the personal computer. Windows 95 and 98 provided an intuitive interface that instantly replaced DOS, with its command lines and DOS-based programs with their arcane codes. While the replacement of DOS programs with Windows-based programs may have been little more than an annoyance for experienced DOS users in the business world, they made it possible for business firms to reduce training expenses, and also for the personal computer to penetrate the household.[13] Because we are interested in the determinants of measured business-sector productivity, it is important for us to distinguish between the benefits of computers in business firms and for consumers in the household, and we shall return to this theme below.

But the "killer application" that powered the post-1995 productivity revival was the marriage of computer hardware and Windows-type software to communications technology that made possible the WWW. Equally important were developments in hardware power and software that made it trivial to send documents as e-mail attachments, thus eliminating the need to print out many preliminary documents and spreadsheets and to send the printed

13. I am one of those experienced DOS users who still writes papers like this one on Wordperfect for DOS 6.0. My fingers automatically know that CTRL+F7,1,1 creates a footnote and that SHIFT+F8,7,6,u will insert an "up" vertical advance code. But those examples underline the training cost faced by business firms ten years ago and the barriers to household adoption of PCs.

versions via fax or courier service. Cheap communications caused a revolution in business practice such as those emphasized by Y-B in our discussion of Puzzle #2; now proprietary systems for electronic communication within firms, and between firms and suppliers, could be replaced by generic systems based on web software that combined transparent interfaces with security protection. In short, the "marriage" of computer hardware with software and communications hardware in the 1990s was as important to the development of the computer as was the development of paved roads and then superhighways to the full exploitation of the internal combustion engine.

Productivity-enhancing Innovation Goes Beyond the ICT Sector

We know that productivity growth accelerated after 1995, and we can speculate as above about the aspects of ICT innovation that helped this acceleration to occur. But the simultaneous acceleration in productivity growth and in ICT investment as a share of GDP amounts, at least in part, to circumstantial evidence. Other aspects of innovation were occurring as well, and these may be as important as ICT in explaining the outstanding productivity performance since 1995 of the retail trade sector.

This performance did not occur evenly across the board in retailing but rather was concentrated in "large stores offering a wide array of goods accompanied by low prices and relatively high use of self-service systems" (Sieling *et al.* 2001, p. 10). A complementary finding by Foster *et al.* (2002) based on a study of a large set of individual retail establishments shows that *all* of retail productivity growth (not just the revival but the entire measured amount of productivity growth over the decade of the 1990s) can be attributed to more productive entering establishments which displaced much less productive existing establishments. The average establishment that continued in business exhibited zero productivity growth, and this despite the massive investment of the retail industry in ICT equipment that presumably went to both old and new establishments. In the Foster results, productivity growth reflects the greater efficiency of newly opened stores, and the Sieling comment implies that most of these highly efficient new stores were large discount operations, the proverbial "big boxes" like Wal-Mart, Home Depot, Best Buy, Circuit City, and new large supermarkets.

The Sieling and Foster findings seem to conflict with the Oliner-Sichel implication in Table 3, at least for the period through 1999, that all of the productivity revival in retailing was achieved by purchasing new computers, software, and communications equipment. All retailers, whether new estabilishments of the 1990s or older establishments of the 1980s or prior decades, have adopted ICT technology. Bar-code readers have become universal in new and old stores. It is likely that the productivity revival in retailing associated with newly built "big box" stores involves far more than the use of computers, including large size, economies of scale, efficient design to allow large-volume unloading from delivery trucks, stacking of merchandise on tall racks with fork-lift trucks, and large-scale purchases taken by customers to vehicles in large adjacent parking lots.

In the taxonomy of Table 3, these sources of efficiency gains should count as a contribution of non-ICT capital (i.e., big-box structures and fork-lift trucks) and organizational improvements that raise MFP in the non-ICT sector. In the latest results of O-S in the right column of Table 3, there has been a substantial acceleration in the contribution to MFP growth of "other nonfarm business" outside the ICT sector, and some of these innovations in retailing may be showing up there. The role of non-ICT capital and non-ICT innovations may also help us to understand the failure of Europe to experience a post-1995 productivity revival, as discussed below in connection with Puzzle #5.

Puzzle #4. Will Continuous Innovation Revive ICT Investment?

Interpretations of the interplay between ICT investment and the post-1995 productivity revival are both of academic interest and also of enormous historical importance in trying to assess whether the rapid productivity growth of 1995-2003 can continue, whether it requires the "support" of a revival in ICT investment, and indeed whether that revival will occur. This section goes back to fundamentals in the economics of economic growth to argue that the contribution to productivity growth of capital deepening and MFP are not independent, as they appear to be in Table 3, but rather are both ultimately dependent on the pace of innovation. This will then lead us to speculate on the likely pace of innovation over the next few years and to distinguish between those aspects of innovation that will provide a further boost to business productivity from those that will mainly provide consumers with improved or additional entertainment options.

The Pace of Innovation is Measured by Growth in Labor Productivity, not MFP

Standard growth accounting exercises such as the O-S decomposition displayed in Table 3 above seem to make growth in labor productivity depend on a contribution of capital deepening and a contribution of MFP growth, as if these two were independent. Dale Jorgenson with many co-authors, originally with Zvi Griliches (Jorgenson-Griliches 1967) and more recently with Kevin Stiroh (Jorgenson-Stiroh 2000), has argued that the driving forces in economic growth are increases in the quantity and quality of inputs, with only a small remaining role for MFP, the residual that usually is taken to measure the importance of technical change.

In thinking about the future of productivity growth and its determinants, we need to flip the Jorgenson approach on its head. The basic argument was developed in Gordon (1968, reprinted in 2003c) and independently by Thomas K. Rymes (1971). A simple example demonstrates the deep truth that capital deepening -- that is, the growth in the capital-labor ratio -- must be directly attributable to innovation. If in the year 1770 all capital equipment consisted of vintage 1770 Watt-Bolton steam engines, and if technical change was all disembodied (that is, figuring out how to rearrange the Watt-Bolton steam engines to boost production) then capital accumulation would have ground to a halt within a few decades of 1770, exhausted by diminishing returns. The entire contribution of capital deepening to labor productivity growth since 1770 is attributable to trillions of dollars of investment in railroads, autos, trucks, airplanes, electrical machinery, oil refineries, computers, and much else, that was invented and further developed after 1770 and would not have occurred without those post-1770 inventions. Or, in the evocative words of Evsey Domar, without technical change capital accumulation would just amount to "wooden ploughs piled up on top of existing wooden ploughs" (Domar, 1961, p. 712).

This point applies only to capital deepening, not to all capital accumulation. Technical change is not necessary for growth in the capital stock that keeps pace with growth in labor input, maintaining a fixed capital-labor ratio; investment would then be entirely devoted to equipping the additional members of the population with additional machines of a given technology, whether wooden ploughs or personal computers. But because all capital deepening ultimately requires technical change, existing measures of multi-factor productivity (MFP) growth cannot be interpreted as measuring the pace of technical progress, since the capital-deepening effect (due also to technical change) is subtracted out in calculating MFP growth.

Standard growth analyses include corrections for changes in the "quality" of capital in addition to its quantity (included but not shown separately in Table 3), and for changes in the "quality" of labor (shown in line 8 of Table 3). Yet changes in the quality of both capital and labor require technical change, just as does capital deepening. Capital's quality improves when the composition of capital input shifts from long-lived assets like structures to short-lived assets like computers, because short-lived assets need to earn a higher marginal product in order to "pay for" their higher rate of depreciation. Yet the very shift from structures to computers reflects technical change that allows the relative price of computers to structures to decline continuously. Even the quality of labor depends on technical change. As shown in Gordon (1968), the returns to education are endogenous as well to the pace of technical change, in the sense that workers in the research sector paid to develop innovations would not be paid as much if they had no creative ideas. This point is still not widely recognized.[14]

These points can be applied to a further understanding of the productivity revival of the late 1990s in the United States. Calculations like those of Table 3 show that after 1995 MFP growth revived, indicating an acceleration of technical change, but this understates the role of technical change, which together with an abundant supply of capital directly created the investment boom and hence the capital-deepening effect of the late 1990s. The post-2000 collapse of the investment boom may signal that the underlying pace of innovation began to slow, and in turn this raises questions about future advances in innovation and ICT investment.

Thinking About the Productivity Implications of Future Innovation

Speculating about future innovation opens up a huge array of topics, but fortunately

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14. This is part of a broader point in the study of cross-country differences in economic growth. Many of the so-called "causes" of economic growth, e.g., education, are themselves in large part the consequence of growth. Countries as they become richer can afford to spread the bounty to education, research subsidies, better infrastructure, and better justice systems that reduce crime and corruption.

only a subcomponent of innovation is relevant for future changes in measured business productivity. Many ongoing innovations are providing higher quality entertainment and communication options to consumer households, but that is not relevant to business productivity. The consumer surplus created by such consumer-oriented innovations is typically missed by price indexes when new products are introduced. While final product is understated by the omission of the benefits of these innovations, at least price indexes today are revised more often than in the past to track the price declines of new consumer products after they are introduced. Past examples of long delays in the introduction of consumer durable goods into the U. S. Consumer Price Index include a 35 year delay for automobiles, a 12 year delay for room air conditioners, and a nine-year delay for the VCR.[15]

Between 1996 and 2000 the annual growth rate of investment in computer hardware doubled to 40 percent from around 20 percent in the previous decade. This acceleration reflected the working of both supply and demand. On the supply side, an acceleration of technical change created a faster rate of decline of computer prices per unit of performance, and this generated an increased demand for computers through a standard substitution effect. On the demand side, the demand for new computer hardware was raised by a set of five factors that were important at the time but did not persist beyond the year 2000. As argued in Gordon

15. New price indexes and an assessment of official price indexes for consumer appliances and automobiles is provided in Gordon (1990), Chapters 7 and 8. A recent assessment of the problem of introducing new goods into price indexes is provided by Schultze and Mackie (2002), Chapter 5.

(2003a), the first of these factors that stimulated the demand for computers, but only for a temporary period, was that the WWW could only be invented once. By the year 2000 most firms, government agencies, and other organizations had invested in the initial construction of their web sites, and further developments and refinements required lower levels of investment in software engineers and computer hardware. Second, much of the computer hardware and software development was purchased by "dot.com" internet start-up companies that promptly went out of business, indicating that their hardware and software investment yielded a negative rate of return. Third, a new generation of user-friendly but memory-hogging business software, notably Windows 95 and 98 and Office 97, both required the purchase of new computers and also revolutionized business productivity by finally creating a universal business language that facilitated networking and electronic exchange of documents and data. But this revolution was temporary as well; since 1998 the exponential growth of computer power has far outrun the pace of innovation in business software. Today's Office XP functions almost identically to Office 97, which was introduced six years ago. Fourth, the "Y2K" crisis led to an artificial compression of the replacement cycle for computer hardware and software investment into the 1998-99 period, both boosting investment in those years and depressing investment in 2000 and beyond. Fifth, deregulation of the telecommunications industry in 1996 led to a free-for-all of investment in the late 1990s that left the U. S. vastly oversupplied with fibre-optic communications capacity, only a small fraction of which is being utilized.

Rapid productivity growth since 1995 combines the one-time-only aspects of the measured portion of the ICT investment boom during 1995-2000, with the disequilibrium argument of Y-B that current productivity growth is being propelled by intangible investments made during the boom years, even after the programmers-consultants-trainers who produced that intangible capital have been laid off, thus further boosting labor productivity by reducing its denominator. To project a repetition of the 1995-2003 experience, and to believe that the HP trend of Figure 1 is actually relevant to future productivity growth over the next five to ten years, we need to look for sources of innovation that could possibly generate another ICT investment boom of the magnitude of the late 1990s.

It is useful to think of inventions as having different levels of fundamental importance, both in terms of their initial effects and in terms of their potential spin-offs and complements. Electricity and the internal combustion engine were mega-inventions, both for their direct effects and the number and importance of their spin-offs (consumer appliances, air conditioning) and complements (roads, superhighways, suburbs, supermarkets). The semiconductor, computer chip, and digitalization taken together represent a first-rate invention, if not a mega-invention. Some of the spinoffs of electricity, like television and the motion picture, were first-rate inventions, albeit nevertheless spinoffs. Down another level were products like the VCR, at best a second-rate invention that combined motion pictures with television. The computer and personal computer are first-rate inventions that have created first-rate complements, namely the WWW and internet. But the PDA, internet-accessible mobile phone, and wi-fi enabled laptop are second-rate inventions at best, themselves representing spinoffs of the previous merging of computer hardware, communications hardware, and software that occurred in the 1990s.

Unfortunately, most of the excitement about current and near-term future innovations in the ICT industry involve second-rate inventions of either consumer or business products. Consumers may be thrilled about their digital cameras, camera phones, flat plasma TV screens, and ever-more-exotic game-playing machines, but these innovations are a continuation of previous incremental improvements and in any case have few if any implications for future business productivity growth.[16] For true consumer impact, none of these innovations creates the kind of quantum jump in consumer welfare that was achieved by the refrigerator, automatic washing machine, dishwasher, the first black-and-white televisions, the first color televisions, the room air conditioner and then central air conditioning. Nevertheless, much of the dynamism in electronic innovation currently and in the future revolves around consumer entertainment, and it has been argued that the average home user now needs greater processing power than the average business employee working at a desk.

Innovations likely to stimulate ICT investment spending for business productivity

16. Consumer electronic spending could stimulate business productivity through a subtle link. Consider two classes of consumer products, electronic products with relative price declines and productivity increases, and non-electronic products with small relative price increases and slightly below-average productivity growth. Innovations that cause consumers to shift their budget share toward more consumer electronic products could raise the growth-rate of economywide productivity.

purposes over the next few years are already known. Another round of miniaturization is at hand, with improved internet capability of Personal Digital Assistants and cellular phones. The rush to compress e-mail and web access onto tiny screens of PDAs with tiny or nonexistent keyboards will clash head-to-head with the rapid spread of wi-fi hotspots that will extend the utility of laptop computers and make it easy to enjoy e-mail and web access from virtually anywhere with a full-sized screen and full-sized keyboard. The ability of business employees to hook up everywhere and anytime, whether by PDA, cell phone, or wi-fied laptop, raises additional issues about work hours. If travel time becomes worktime, and business employees feel that they must be accessible 24/7, including while on vacation, then the productivity data may overstate the level of productivity by understating the level of hours.[17] Looking further ahead, it is easy to foresee the day when keyboards are no longer necessary for PDAs, when e-mails can be composed by voice-recognition sofware, and incoming e-mail can be automatically translated by computer voice and transmitted over tiny earphones.

One way of assessing the likely productivity impact of near-term ICT innovation is to ask whether such innovations can break through the inherent impediments to the replacement of human beings by computers. As I argued in Gordon (2000, pp. 65-66), some uses of labor are immune to replacement by computers, including airline pilots, truck drivers, doctors, nurses, dentists, lawyers, professors, investment bankers, management consultants, bartenders, wait

17. This point has long been made by Stephen Roach of Morgan Stanley.

staff, bus boys, flight attendants, barbers, lawn maintenance services, auto repair, hotel housekeepers, and almost every type of home maintenance. Innovation operates around the edges but does not change the nature of these jobs fundamentally. For the first time at a recent visit my doctor used new (at least for him) software in the examination room that allowed him to scan previous test results, current prescriptions, and to issue new prescriptions by checking a few boxes. But as a byproduct he spent most of the visit looking at his computer screen rather than examining me! Professors are on this list as a species unlikely to be replaced by computers, but professors have been affected by ICT investments. In my case the office-productivity innovations of the 1990s, particularly Excel and e-mail attachments, have made it possible for my research assistants to send me 10 or 20 rounds of results per day without ever talking to me in person. But those innovations were all in place by 1998 and little on the horizon has appeared that remotely approaches their importance.

A different but equally skeptical view is offered by Carr (2003).[18] In his view, the failure of the dot.coms in the late 1990s reflected a pervasive tendency of ICT innovation to be easily copied, thus quickly eroding the competitive advantage for any one company that is essential for ICT investments to be profitable. Benefits for consumers and improvements in productivity come at the price of reduced or negligible corporate profitability and the erosion of incentives to undertake the next round of investment. In the past such innovations as American Airlines'

18. The following discussion of Carr's views comes from [no author], "Nick Carr: The Tech Advantage is Overrated," *Business Week*, August 18-25, 2003, pp. 82-84.

Sabre reservations system provided a competitive advantage for a decade or more because they were so hard to copy, but recent developments "toward openness, toward standardization, toward greater power, toward ever more powerful hardware and software" have greatly eased the task of competitors wanting to copy a single company's initial innovation. Carr's argument comes down to diminishing returns, the same force that Gordon (2000) argued makes it ever more difficult to think up truly important innovations for business productivity. In Carr's words, "a lot of the core things that businesses do have already been automated with information technologies."[19]

Even optimists like Intel's Andy Grove project a recovery of ICT investment, but one based on "more of the same" rather than any important new innovations. In Grove's view, the continuing exponential growth of e-commerce at those dot.com firms which survived the 1990s shake-out will inevitably require sizeable further investments to "light [presently unutilized] fibre" and to handle ever-growing e-commerce transactions. Grove agrees that the investment boom of the late 1990s was "unsustainable," and his favorite examples of the future potential growth in ICT investment seem remote from business productivity, including "digital distribution of music," "digital electronics applied to warfare," and use of ICT in the health care industry.[20]

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19. The two quotes come from the previously cited *Business Week* article, pp. 83-84.

20. This paragraph and its quotes come from [no author] "Andy Grove: We Can't Even Glimpse the Potential," *Business Week*, August 18-25, 2003, pp. 86-88.

The operation of diminishing returns makes it difficult to believe that over the next five or ten years innovation related to business productivity will be sufficiently dynamic to allow a repeat of the ICT investment boom of the late 1990s. Because innovation is the ultimate driver of the capital-deepening process, it is possible that the ebullient 2000-2003 performance of U. S. productivity growth summarized in the HP trend line of Figure 1 may prove to be a historical high-water mark of productivity growth.

Puzzle #5: Why has Europe failed to experience a productivity growth revival?

Europeans are perplexed by the failure of Europe (i.e., the European Union) to experience a post-1995 productivity growth revival. In fact, Europe experienced a substantial post-1995 productivity growth slowdown, as shown in Table 4. The initial European slowdown evident in data for 1995-2000 worsened with data for 2000-2003, whereas the U. S. (as we saw above) experienced accelerating productivity growth at the cost of rapidly declining hours of work during 2000-2002. All the data in Table 4 are taken from a recent Conference Board pamphlet by McGuckin-van Ark (2003). Readers should note that international comparisons are based on data on GDP per hour for the entire economy including the government sector, and these generally display slower growth rates of productivity than the data for the nonfarm private business sector that we examined in Table 1 and Figure 1 above.

The right-hand column of Table 4 displays the *change* in output, hours, and output per hour between 1990-95 and 1995-2003. Surprisingly, the post-1995 acceleration in output growth was only slightly less in Europe as in the U. S., 0.6 vs. 0.9 percentage points, respectively. But Europe's performance in hours of work was the diametric opposite of the U. S., accelerating by almost two percentage points compared to pre-1995, whereas hours growth in the U. S. was flat. As a result, the productivity change between 1990-95 and 1995-2003 was the mirror image of the hours change, with an acceleration of 0.9 percent for the U. S. and a deceleration of more than one percent for Europe.

Most of the literature on the failure of Europe to achieve a post-1995 productivity growth acceleration treats Europe as overregulated and stuck in the mud, ignoring the turnaround from hours contraction to hours expansion before and after 1995. In this section we review recent findings on the Europe-U. S. difference in a search for useful conclusions. An initial reaction is that this difference appears to deny the kind of importance for ICT investment in causing the post-1995 U. S. revival that appears in the decomposition of O-S in Table 3. Business firms, not to mention university professors, use the same PCs and Microsoft software everywhere in Europe, and Europe is widely acknowledged to be ahead in the use of mobile telephones. This reaction provides further circumstantial evidence that the O-S growth accounting exercise in Table 3 may overstate the contribution of ICT investment to the U. S. post-1995 revival.

Aggregation, Retailing, and Regulation

Part of the European puzzle is resolved when we recognize that heterogeneity among European countries is more pronounced than the difference between the European Union and the U. S. Numerous studies have shown a relatively strong positive correlation between MFP growth and measures of ICT intensity, e.g., the ratio of ICT expenditure to GDP or the change in PC intensity per 100 inhabitants over the 1990s. In such comparisons, numerous countries achieved higher MFP growth rates than the U. S. over the 1990s, including Ireland, Finland, Sweden, Denmark, Norway, Canada, and Australia. Some, but not all, of these countries surpass the U. S. in PC intensity and/or in the share of ICT expenditure. What differs most between Europe and the U. S. is the low level of PC adoption and ICT expenditure in the "olive belt" ranging from Portugal and Spain on the west to Italy and Greece in the east.[21]

A comprehensive recent study by van Ark *et al.* (2002) provides a few answers at a more formal level. It allows us to trace the location of productivity growth accelerations and decelerations to particular industrial sectors, divided into ICT-producing, ICT-using, and non-ICT industries. The core of the U. S. success story appears to have been in *ICT-using* industries, i.e., the same wholesale, retail, and securities trading industries already discussed above. The decomposition of van Ark *et al.* (2002, Figure 2a) shows that literally *all* of the productivity growth differential of the U. S. over Europe in the late 1990s came from these three industries, with retail contributing about 55 percent of the differential, wholesale 24 percent, and securities

21. Scatter plots supporting these correlations between MFP growth and computer intensity are presented in Bartelsman *et al.* (2002, Figures 8 and 9).

trade 20 percent. The remaining industries had small positive or negative differentials, netting out to zero. As might have been expected, the U. S.-Europe differential was negative in telecom services, reflecting U. S. backwardness in mobile phones.

These results for Europe link to our discussion of retailing in the previous section; the retail sector was a major factor explaining Europe's poor performance in the late 1990s. Just as we argued earlier that the U. S. retailing sector has achieved efficiency gains for reasons not directly related to computers, including physical investments in a new type of "big box" organization, so we can suggest in parallel that Europe has fallen behind because European firms are much less free to develop the "big box" retail formats.[22] Impediments include land use regulations that prevent the carving out of new "greenfield" sites for "big box" stores in suburban and exurban locations, shop-closing regulations that restrict the revenue potential of new investments, congestion in central-city locations that are near the nodes of Europe's extensive urban public transit systems, and restrictive labor rules that limit flexibility in organizing the workplace and make it expensive to hire and fire workers with the near-total freedom to which U. S. firms are accustomed.

A complementary interpretation is provided in a cross-country study of productivity differences in the service sector by the McKinsey Global Institute (1992). Their set of policy

22. Any generalizations here about "Europe" must be qualified by differences across countries. The Germans until recently were notorious for restrictive shop-closing hours, while the French firm Carrefour and the Swedish firm Ikea are innovators in "big box" retailing formats.

recommendations (Chapter 2-D, pp. 13-14) seem as relevant today as when written a decade ago and echo the previous paragraph by pointing to impediments to the development of modern retailing in some but not all European countries. European policymakers have adopted a set of policies that encourage high density and a concentration of retailing activity in the central city. The development of modern "big box" retailing formats has been hindered by these policies and the resulting high cost of real estate and the complex and precarious process of obtaining planning approval for large plots of land.

An issue identified by McKinsey is the role of resale price maintenance policies that in the U. S. assure new competitors that they will be able to attain the same access to suppliers at roughly the same prices as existing retailers. In contrast, in some European countries producers refuse to discount to new, high-volume, low-cost retailing formats in order to protect smaller high-cost merchants. In some European countries, regulations directly prohibit the entry of large-scale stores and/or limit store opening days and hours, thus preventing large stores from fully amortizing their investments.

A partial survey of other cross-country studies reveals a disappointing lack of specific conclusions at the level of the van Ark *et al.* and McKinsey studies. The typical study conducts a growth accounting exercise, concludes that Europe has lagged behind the U. S. in adopting ICT technology to a greater or lesser degree, does not trace differences in behavior to specific industries, and concludes with a general plea for unspecified structural reforms. Among the studies that fit this characterization are Colecchia and Schreyer (2001), Daveri (2002), Rhine-Westphalia Institute for Economic Research (2002), and Vijselaar and Albers (2002).

Economic Institutions and Culture

A refreshing contrast is provided by Phelps (2003), who takes a broader view of economic institutions that promote economic "dynamism" and those that suppress it. His analysis of "dynamism" starts from Schumpeter's concept of "creative destruction". He adds to Schumpeter's emphasis on entrepreneurship an equal if not greater emphasis on "financiership," that is, the ability of financial markets to steer finance to worthy innovations. The greater success of the U. S. in encouraging innovation is attributed in part to its greater emphasis on venture capital and initial public equity offerings (IPO) than in Europe.

In Phelps' view, the relatively poor economic performance of continental Europe results *both* from the underdevelopment of capitalist institutions like venture capital and equity finance, and the overdevelopment on corporatist institutions which suppress innovation and competition. These corporatist institutions impose "penalties, impediments, prohibitions, and mandates . . . generally intended to damp down creative destruction." Among these impediments are licenses and permissions to set up a new plant or firm, the need to consult with workers on changes in the mix of products or plants, and employment protection legislation. Because these institutions are designed to dampen down the changes inherent in "unbridled capitalism," they also lead to the underdevelopment of the stock market, resulting in lower ratios of stock market valuation to GDP in continental Europe than in the U. S. and other less corporatist economies like Britain, Canada, and Australia.

Phelps provides a complementary analysis of cultural differences between Europe and the U. S. Europeans view with disdain the money-grubbing Americans with their out-sized rewards for CEOs and successful entrepreneurs. American children begin to work earlier than European children, earning baby-sitting money in their early teens, working in fast-food outlets while in high school, and are forced to work during college in contrast to European youth who "free ride" on government-paid college tuition and stipends. Phelps concludes that Europe has developed a culture of "dependency" that "breeds an unduly large share of young people who have little sense of independence and are unwilling to strike out on their own." He might have added that high levels of long-term youth unemployment discourage independence and encourage young adults to live with their parents in their 20s and, in Italy, into their 30s.

Caveats

Europeans do not take these criticisms lying down. Yes, they admit that high youth unemployment, low labor force participation, and a generation of young adults living with their parents represents an economic and social failure. But they are quick to criticize aspects of American economic and political institutions that, while making it easy for Wal-Mart and Home Depot to find the land to build thousands of "big box" stores, has offsetting disadvantages.

Europeans find abhorrent the hundreds of billions, or even trillions, that Americans have spent on extra highways and extra energy to support the dispersion of the population into huge metropolitan areas spreading over hundreds or even thousands of square miles, in many cases with few transport options other than the automobile. Productivity data do not give Europe sufficient credit for the convenience benefits of frequent bus, subway, and train (including TGV) public transit. Excessive American dispersion is viewed as a response to misguided public policies, especially subsidies to interstate highways in vast amounts relative to public transport, local zoning measures in some suburbs that prohibit residential land allocations below a fixed size, e.g., two acres, and the infamous and politically untouchable deduction of mortgage interest payments from income tax.

Europeans enjoy shopping at small individually owned shops on lively central city main streets and pedestrian arcades, and recoil with distaste from the ubiquitous and cheerless American strip malls and big-box retailers — although Carrefour, Ikea, and others provide American-like options in some European cities. To counter the effects of American land use regulations that create overly dispersed metropolitan areas, Europeans counter with their own brand of land use rules that preserve greenbelts and inhibit growth of suburban and exurban retailing. A more complete consideration of these differences leads to the conclusion that GDP data understate the Europe/U. S. ratio of both productivity and real GDP per capita (see

Gordon, 2002).

Conclusion

This paper began with five puzzles, and we are now prepared to provide some tentative resolutions. Puzzle #1 asked about the "cyclical effect" that was invoked in discussions of the early 1995-99 portion of the post-1995 U. S. productivity revival to argue that the revival was in part temporary, and that unsustainably rapid growth in output had created unsustainably fast growth in productivity. The further acceleration of productivity growth in 2000-03 has laid the cyclical argument to rest insofar as it applies to the 1995-99 period. But another cyclical phenomenon has emerged more recently, the "early-recovery productivity bubble" that pushed up productivity growth in 2002 to incredible levels. This phenomenon is cyclical in the sense that it is periodic; similar "bubbles" occurred in 1975-76, 1982-83, and 1991-92, and in each case were followed by two or more years of productivity growth below trend. Data on productivity growth rates during 2000-03 are pushed up by the bubble phenomenon, as are estimated Hodrick-Prescott productivity trends that respond relatively rapidly to the evolution of the actual data.

Puzzle #2 was suggested by the paradox that productivity growth accelerated after the year 2000 despite the collapse in the ICT investment boom, raising the possibility that standard studies of growth accounting may exaggerate the causal role of ICT in achieving the first 1995-99 phase of the productivity revival. Three factors support the case for exaggeration. First, the growth accounting methodology unrealistically assumes that the full productivity benefits of ICT hardware and software are achieved at the instant of production, with no allowance for reorganization or training effects. Second, independent evidence for the retail trade sector finds that all of the rapid productivity growth in the 1990s was achieved by new establishments and none by old establishments, even though ICT investment has been made in both. Third, and most important, the boom in measured ICT investment in the late 1990s was accompanied by a boom of perhaps equal size in unmeasured or "hidden" improvements in intangible and human capital, as suggested by Yang and Brynjolfsson. The numerator of productivity omitted the creation of the intangible capital but the denominator included the labor input, artificially holding down the magnitude of the productivity growth revival. Then after 2000 productivity growth was exaggerated, because output was supported by intangible capital input that had been created before 2000, but the labor input that had created the intangible capital had declined, as programmers, consultants, and trainers were laid off. The cyclical analysis of the 2002 productivity growth "bubble" and the intangible capital argument both suggest that observed productivity growth in 2002-2003 may represent a high water mark and cannot be expected to continue.

Puzzle #3 poses the paradox that technological change in computers has apparently proceeded at a relatively steady pace, judging by the relatively constant rate of price decline of computer power and the relatively exponential rate of increase of the performance-price ratio, yet the payoff from computer innovation in the form of productivity growth occurred in the late 1990s but not in the 1970s or 1980s. Drawing on analogies from the Great Inventions of the late nineteenth century, electricity and the internal combustion engine, we pointed to miniaturization and the development of complementary innovations as common threads linking the Great Inventions to the development of computers. The key development of the 1990s was the marriage of computer and communications technology with software that made possible the internet, the WWW, and the pervasive spread of the mobile telephone. Yet some of the productivity growth revival of the 1990s was not directly attributable to this ICT marriage, but rather, especially in the retail trade sector, reflected the benefits of an organization revolution and large scale that made possible the "big box" retail phenomenon.

Puzzle #4 focusses on the chicken-egg interrelationship between productivity, investment, and innovation. That major source of productivity growth, capital-deepening investment, cannot occur forever without a continuous flow of innovations, and so the post-2000 crash in ICT investment raises the question as to whether the wave of innovation in the 1990s had a one-time-only component, and whether a new wave of innovations will emerge over the next few years to create a repetition of the investment boom. We classify innovations as "mega," "first-rate", "second-rate," and beyond and argue that the marriage of computer and communications hardware with software in the 1990s was a first-rate invention, but that it had a one-time-only component because the web could only be invented once, because part of the boom consisted of demand from dot.com firms which promptly went bust, because of the mismatch between hardware and software innovation, because of the timing of Y2K, and because of the overbuilding of telecom infrastructure. The main areas of ICT investment in the near future are innovations that look distinctly second-rate, the further move toward mobility with internet-enabled mobile phones and wi-fi enabled laptops that will allow e-mail, web access, Word, Excel, and Powerpoint to be accessed more conveniently, but the functions to be accessed will be the same as five years ago.

The final puzzle #5 is why Europe failed to exhibit any sign of a post-1995 productivity growth revival, despite its use of the same hardware and software and its evident lead in mobile telephony. References to "Europe" disguise a wide variety of performance, with Ireland and Finland exhibiting much faster productivity growth than the U. S., but "olive belt" nations like Italy and Greece scoring low on productivity and ICT investment (except for mobile phones). Disaggregated studies of industrial sectors suggest that the main difference between Europe and the U. S. is in ICT-using industries like wholesale and retail trade and in securities trading, the same industries that were discussed above as leading the vanguard of computer using industries. Yet the contrast in retailing calls attention to regulatory barriers and land-use regulations in Europe that inhibit the development of the "big box" retailing formats that have created many of the productivity gains in the U. S.

Phelps provides a unifying framework in which economic dynamism is promoted by policies that promote competition and flexible equity finance and is retarded by corporatist institutions which are designed to protect incumbent producers and inhibit new entry. He also points to European cultural attributes that inhibit the development of ambition and independence by teenagers and young adults, in contrast to their encouragement in the U. S. While competition, corporatism, and culture may help to explain the differing evolution of productivity growth on the two sides of the Atlantic since 1995, they reveal institutional flaws in both continents that are inbred and likely to persist.

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Figure 1. Four-Quarter Change in U. S. Productivity and Alternative Trends, 1955-2003

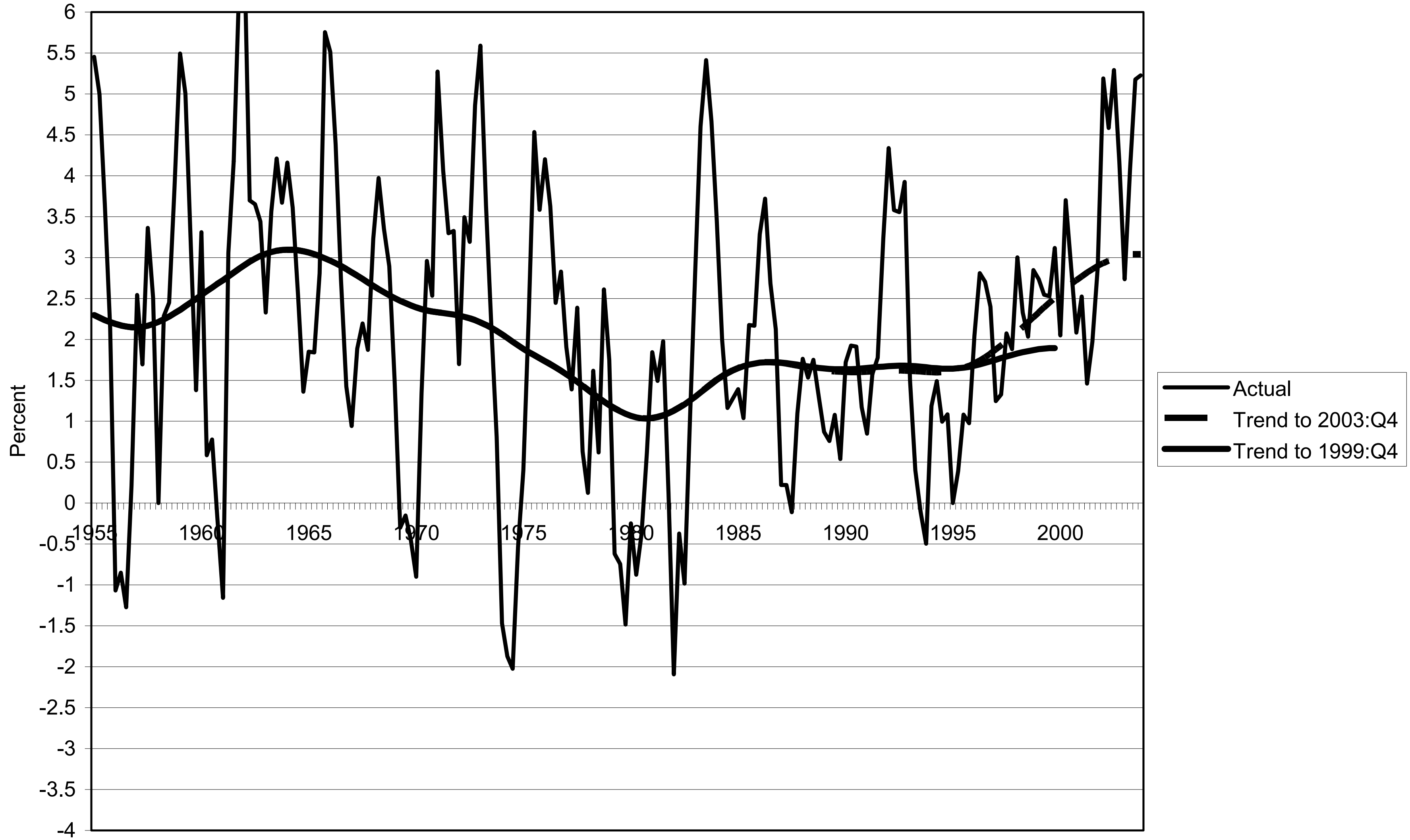

TABLE 1

Annual Percentage Rate of Change of U. S. Nonfarm Business Output per Hour, Actual and Estimated Trends, Selected Intervals, 1950-2003

	Actual	Trend with Data to 99:Q4	Trend with Data to 03:Q2	Cyclical Effect Trend to 99:Q4	Cyclical Effect Trend to 03:Q2
1950:Q2-1972:Q2	2.60	2.64	2.64	-0.04	-0.04
1972:Q2-1995-Q4	1.53	1.59	1.58	-0.06	-0.05
1995:Q4-1999:Q4	2.35	1.81	2.08	0.54	0.27
1999:Q4-2003:Q2	3.50	------	2.87	------	0.63
1995:Q4-2003:Q2	2.93	------	2.48	------	0.45
Addendum: Cyclical Effect Estimated in Gordon (2000)					
1995:Q4-1999:Q4	2.75	2.25	------	0.50	------

Sources for Top Section: Actual from BLS, Trends estimated with HP filter 6400 parameter, cyclical effect equals actual minus appropriate trend

Gordon Source: Gordon (2000), Table 2, p. 55.

TABLE 2

Decomposition of Bubble Periods,
Alternative Intervals, Four-quarter Rates of Change

Four Quarters Ending in Stated Quarter	1976:Q2	1983:Q4	1992:Q1	2002:Q3
1. Deviation of Actual Change from Trend	2.77	3.22	2.43	2.79
2. Explained by Lagged Adjustment	1.50	0.53	0.11	-0.24
3. Explained by End-of-Expansion Effect	2.07	2.61	1.70	1.01
4. Unexplained Residual (1-2-3)	-0.80	0.08	0.62	2.02
5. Actual Change from Trend, next 2 years	-0.4	0.11	-0.51	2.26
6. Deceleration in following 2 years (5-1)	-3.17	-3.11	-2.94	-0.53

Note: Deceleration in line 6 refers to 5 quarters, 2002:Q4-2003:Q4

Source: Gordon (2003b, Table 8, p. 243)

TABLE 3

Estimates by Oliner and Sichel of the Contribution of ICT Capital to the post-1995 Productivity Revival, Annual Percentage Rates of Change

	Original O-S (2000)			Latest O-S (2003)				
	1973-95	1995-99	*Change*	1973-95	1995-99	*Change*	1995-2002	*Change*
1. Labor Productivity	1.41	2.57	***1.16***	1.41	2.36	***0.96***	2.61	***1.20***
Contributions from:								
2. Capital Deepening	0.77	1.10	***0.33***	0.72	0.98	***0.26***	1.20	***0.49***
3. ICT Capital	0.46	0.96	***0.50***	0.42	0.95	***0.53***	0.93	***0.51***
4. Computer Hardware	0.25	0.59	***0.34***	0.22	0.52	***0.31***	0.47	***0.25***
5. Software	0.12	0.27	***0.15***	0.12	0.33	***0.20***	0.33	***0.21***
6. Communication Equipment	0.08	0.10	***0.02***	0.08	0.09	***0.01***	0.13	***0.05***
7. Other Capital	0.31	0.14	***-0.17***	0.30	0.03	***-0.26***	0.27	***-0.02***
8. Labor Quality	0.27	0.31	***0.04***	0.27	0.30	***0.03***	0.25	***-0.02***
9. Multifactor Productivity (MFP)	0.36	1.16	***0.80***	0.42	0.98	***0.56***	1.15	***0.74***
of which contributed by:								
10. ICT/semiconductor	0.22	0.66	***0.44***	0.30	0.72	***0.41***	0.70	***0.40***
11. Other nonfarm business	0.15	0.50	***0.35***	0.11	0.26	***0.15***	0.45	***0.34***
Memo: Total ICT/Semiconductor Contribution to Labor Productivity								
12. Sum of lines 3 and 10	0.67	1.62	***0.95***	0.72	1.66	***0.94***	1.63	***0.91***
13. Share of line 1 in percent	47.9	63.0	***81.3***	51.6	70.4	***98.0***	62.6	***75.5***

Sources: Original O-S from Oliner-Sichel (2000), Tables 2 and 4. .
Latest O-S from data provided by Daniel Sichel to the author

TABLE 4

Annual Rate of Change of Output, Hours, and Output per Hour, U. S. vs. Europe, 1990-2003

	1990-95	1995-200(	2000-03	1995-200:	1995-2003 vs. 1990-95
United States					
Output	2.4	4.1	2.0	3.3	0.9
Hours	1.4	2.2	0.1	1.4	0.0
Output per Hour	1.0	1.9	1.9	1.9	0.9
European Union					
Output	1.5	2.6	1.2	2.1	0.6
Hours	-1.0	1.1	0.3	0.8	1.8
Output per Hour	2.5	1.5	0.9	1.3	-1.2

Source: McGuckin-van Ark (2004, Table 1).