INFORMATION TECHNOLOGY AND THE NEW ECONOMY

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Abstract

The superior performance of the U.S. economy in the late 1990s has led many commentators to speculate that a "New Economy" has emerged in which heavy investment in information technology (IT) has led to an era of sustained economic growth. Although the recent economic slowdown has dampened some of the enthusiasm for the idea of a New Economy, a fundamental question remains: can the output growth experienced in the late 90's, which was significantly higher than that observed in previous decades, be traced back to IT?

This paper addresses this question by looking at the behavior of labor productivity, a key measure of economic well-being that grew at a significantly faster rate in the late '90s. The New Economy hypothesis to be examined is whether investment in IT caused the acceleration in productivity. The evidence suggests a growing consensus on two conclusions:

- Information technology is an important factor in the recent acceleration in productivity growth.
- Both the production and the use of IT contributed to the productivity revival.

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- Information technology is an important factor in the recent acceleration in productivity growth.
- Both the production and the use of IT contributed to the productivity revival.

Seen in this perspective, the idea of the New Economy is not as fanciful as some recent skeptics would claim.

While forecasting productivity growth is a chancy and often unsuccessful enterprise, there is some reason to believe that the acceleration in labor productivity could persist for several more years. This guarded optimism is informed by a recurrent theme in the literature that investments in IT manifest themselves in higher productivity with a lag of a few years. Thus, the enormous investments made by U.S. firms in IT in the late 90's could possibly show up in productivity numbers well into the first decade of the 21^{st} century.

The rest of the paper is organized as follows: section I introduces some general concepts of productivity analysis, section II explains growth accounting, the standard framework for understanding productivity growth, section III applies this framework to the question of IT's impact on productivity, section IV looks at this question with methods other than growth accounting, and section V concludes.

I. PRODUCTIVITY

In its simplest form, productivity is the amount of output that can be produced with a given amount of input. Labor productivity, then, measures the amount of output produced with a given amount of labor. At the aggregate level this means GDP divided by the total number of hours worked in the economy. This definition highlights why labor productivity is considered such an important measure of the long-term performance of the economy: growth in labor productivity increases the amount of goods and services available for consumption without a corresponding increase in the amount of time spent working. For this reason productivity growth often proxies for the change in the standard of living--the variable that, in the final analysis, most people really care about.

To measure growth in labor productivity involves calculating the ratio of the change in *real* (inflation-adjusted) GDP to the change in hours worked. While determining hours worked presents relatively few measurement problems, calculating the change in real GDP has been a research topic at the center of the New Economy debate. Nominal GDP, which is easily measured, is the product of the price index and the quantity of goods and services sold in the economy. Thus, the percent change in nominal GDP is approximately equal to the percent change in prices (inflation) plus the percent change in quantities (real GDP growth). The problem is how to attribute changes in nominal GDP between changes in prices and changes in quantities. If the type and quality of goods consumed changes very little from year-to-year, as could be expected in an industrial "Old Economy" era, then measuring changes in quantities should be trivial. If, on the other hand, the type and quality of goods available changes rapidly, as is the case with many IT-related New Economy products, then making accurate quality-adjustments to the change in quantities becomes crucial in gaining a true idea of what's going on in the economy. For example, although the price of desktop computers has not changed greatly over the past decade, the quality and power of those computers has soared. To incorporate this observation, the price per unit of computing power, rather than per computer, should have plummeted over this period. In fact, the two agencies responsible for constructing the productivity numbers, the Bureau of Labor Statistics and the Bureau of Economic Analysis, have recognized this problem and have exerted considerable effort in order to insure their numbers accurately reflect the rapid pace of change caused by technological innovation. Despite these efforts, the measurement issues surrounding the New Economy have left lingering debate.

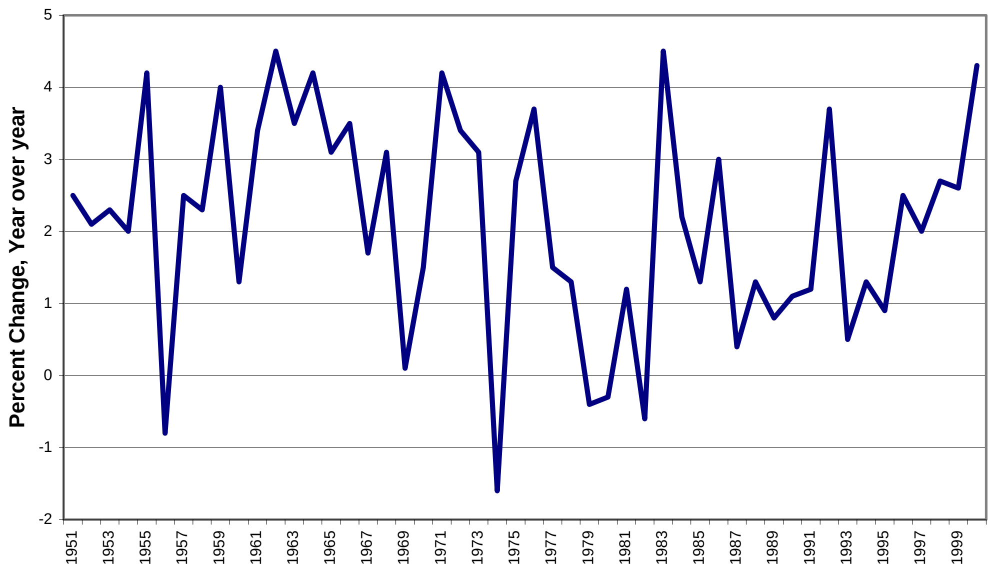
The annual labor productivity growth rates for the past 50 years are presented in Chart 1 (see below). One noteworthy aspect of this series is its procyclical variability. While the relation between the business cycle and productivity has been a topic of intense controversy in recent decades, one feature of this correlation deserves mention. In the presence of fixed costs of hiring and firing workers, economic theory suggests that labor productivity should be procyclical. This idea, known as the 'labor hoarding' theory of procyclical productivity, holds that because firms cannot costlessly adjust the amount of labor input used in response to shifts in output, we can expect aggregate hours to change less than one-for-one in response to changes in aggregate output. Sudden contractions or expansions in output (recessions or recoveries) usually generate drops or jumps in measured labor productivity because firms don't meet these contractions or expansions with immediate and proportional increases or decreases in employment[1].

The procylicality of productivity has two points of relevance for the present discussion. First, this feature of the data indicates why the contraction in labor productivity in the first quarter of 2001 should not necessarily be seen as the death knell

[1] For further discussion, see Basu and Fernald (1999).

of the productivity revival, but rather as a cyclical adjustment. Second, some had claimed that the productivity revival in the late '90s was, in large measure, a reflection of the procyclicality of the productivity series. This view, however, has been subjected to the critique that the cyclical aspect of productivity is usually felt at the beginning of a recovery whereas the productivity revival picked up steam several years into the expansion of the '90s.

Chart 1.
Aggregate Labor Productivity 1951-2000
(Nonfarm Business, BLS)



The productivity growth rates of the recent past can be divided into two sub-periods: 1973-1995, the era of the "productivity slowdown", and 1995-1999[2], the New Economy. Though measurement methodologies differ from study to study, the estimates of average annual growth in aggregate labor productivity for these periods tend to cluster around one and one-half percent for the earlier period and two and one-half percent for the latter period.

This one percentage point difference may not appear terribly important. Yet if permanent, this difference would mean living standards doubling every 28 years rather than every 46 years. Consequently, understanding the determinants of productivity growth has been a major project of contemporary economics.

Nevertheless, both the productivity slowdown and its more recent revival have been somewhat of a puzzle to economists. The deceleration in productivity growth in the 70's and 80's has attracted many candidate causes: among others, high energy prices, increased labor and environmental regulations, and monetary instability. The productivity

[2] This is not to say the New Economy ended in 1999, rather this is the last full year for which the final revision of productivity numbers is available.

revival, on the other hand, has focused attention on one possible explanation--the increased prevalence of IT in the American economy. In order to quantify the impact of IT on labor productivity, economists commonly use a decomposition known as growth accounting.

II. GROWTH ACCOUNTING

The cornerstone of growth accounting is the decomposition of labor productivity growth into a weighted sum of effective capital growth and effective labor growth plus a residual term known as total factor productivity (TFP)[3]. Or,

$$\%\Delta LP = a \cdot \%\Delta k + (1 - a) \cdot \%\Delta l + \%\Delta TFP$$

where uppercase delta refers to change and a is a parameter.[4] Effective capital growth, *k*, refers to the growth in the aggregate flow of capital services minus the growth in aggregate hours worked. Growth in effective capital, also know as capital deepening, has a positive effect on labor productivity because a larger amount of capital per worker should increase the output of that worker. As we will see, capital deepening can be measured for different classes of capital, in particular for deepening of IT capital. Growth in effective labor, *l*, captures the effect of changes in labor quality.[5]

The residual in the growth accounting equation, TFP, is commonly equated with technological change. TFP represents all the increase in output that cannot be accounted for by an increase in any other input. In this sense it is a costless expansion of the economy's set of possible production bundles. It is sometimes said that TFP is "a measure of our ignorance" in that any productivity increase we cannot attribute to a growth in an input factor we lump in with TFP.[6] This is a valid criticism and because of this we should be mindful that TFP can pick up increases in productivity due to process innovations or efficiencies generated by organizational changes. Despite its limitations, growth accounting is a useful framework and remains the starting point for the analysis of economic growth.

III. PRODUCTIVITY AND IT

Information technology can affect aggregate labor productivity through two channels: the *production* of IT and the *use* of IT. Few question that IT production has exhibited phenomenal productivity growth. This is probably best illustrated in the case of semiconductors. In the 1960's Gordon Moore, the founder of Intel, predicted that microprocessor power would double every 18 months. The prediction was accurate

[3] Also known as the Solow residual of multifactor productivity (MFP).
[4] Specifically, under standard assumptions, a is the share of output paid to capital.
[5] The more familiar decomposition of *output* growth is obtained by adding the change in aggregate hours to both sides of the labor productivity growth equation. In either case, TFP is identical.
[6] For a discussion of TFP see Hulten (2000).

enough that it became known as Moore's Law. Even accounting for R&D expenditures, the technological progress of the IT manufacturing sector has been remarkable and has contributed to the acceleration in labor productivity. In growth accounting terms, this contribution should appear as an increase in the TFP of IT-producing industries.

The second avenue through which information technology has the potential to increase labor productivity is though its use. The rhetoric of the New Economy proponents often focuses on the efficiencies that will accrue to firms engaged in activities other than the production of IT but which nevertheless successfully integrate the use of IT into their existing operations. Firms that use IT could expect productivity gains for two reasons. First, the rapid decline in the price of computing power has spurred huge investments in IT. This investment, like any other form of capital spending, should raise the productive capacity of those firms that undertake it. Second, IT has the potential to allow firms to implement efficiency-enhancing changes in the way they do business. These two effects would show up in a growth accounting equation as a capital deepening in IT-using firms and an increase in TFP of IT-using firms. Table 1 summarizes where we would expect the productivity contributions from the use and production of IT to appear in a growth accounting exercise.

Table 1.

	Use of IT	Production of IT
$\%\Delta k$ (Capital deepening)		
IT-capital	X	
All other capital		
$\%\Delta l$ (Labor quality)		
$\%\Delta TFP$ (Total factor productivity)		
IT-producers		X
All other industries	X	

The possible effect of IT use on TFP has attracted considerable attention. It is in this sense that IT could be considered a General Purpose Technology (GPT). As defined by Helpman (1998) a GPT is a "drastic innovation [that] has the potential for pervasive use in a wide range of sectors in ways that drastically change their mode of operation." Similarly, Bresnahan and Trajtenberg (1995) speak of GPT's as "'enabling technologies' opening up new opportunities rather than offering complete, final solutions." A classic example of a GPT is electricity. Around the turn of the century American industry underwent radical change due to the widespread utilization of electricity. Firms invested heavily in electric machinery as the price of electivity relative to other forms of power fell. If these firms didn't change their production process they could still expect an increase in productivity due to this capital deepening. However, as David (1990) points out, the switch from steam to electric power also allowed firms to change the floor plans of their factories in a way that increased efficiency. Thus, firms did change their production process' and hence experienced a second productivity 'kick' from using electricity.

The distinction between production and use of IT has been critical in the debate concerning the impact of IT upon productivity. In a series of papers, Gordon (1999, 2000) has argued that IT's contribution to the acceleration in productivity experienced in the late '90s has been solely through the more efficient production of IT. The use of IT, Gordon claims, has not added to the uptick in productivity. In a certain sense, this distinction is immaterial: nobody denies that productivity did accelerate in the period under question. In another sense, Gordon's interpretation, if true, would have certain implications about the sustainability of the New Economy. The narrow concentration of productivity growth in one sector would make the economy's continued health vulnerable to disruptions in that sector. Furthermore, the efficiency gains in IT production, particularly semiconductors, will eventually run into physical constraints; Moore's Law cannot hold indefinitely. Gordon's reading of the facts, however, has been controversial and as we will see shortly, several studies have found the use of IT to have made a substantial contribution to the productivity revival.

The growth accounting equation has been applied to the two sub-periods mentioned above by a number of economists in order to clarify how and why the pickup in productivity occurred. Growth accounting exercises can produce different results for the same period because there are several choices to be made as to how to measure the aggregate flow of capital and labor services. Three of the most recognized studies include one government survey, BLS (2000) and two academic works, Jorgenson and Stiroh (1999) and Oliner and Sichel (2000). Their findings are presented in Table 2.

Table 2.

	Jorgenson & Stiroh	Oliner & Sichel	BLS
Labor Productivity 1973-1995	1.42	1.41	1.39
Labor Productivity 1995-1999	2.37	2.57	2.30
Acceleration	0.95	1.16	0.91
%Δ*k* (Capital deepening)	0.29	0.33	0.10
IT-capital	0.34	0.50	0.38
All other capital	-0.05	-0.17	-0.31
%Δ*l* (Labor quality)	0.01	0.04	0.06
%Δ*TFP* (Total factor productivity)	0.65	0.80	0.90
IT-producers	0.24	0.31	n.a.
All other industries	0.41	0.49	n.a.

All three surveys decompose the approximately one percentage point acceleration in productivity growth into the standard categories of capital deepening, increased labor quality, and TFP. Furthermore, these studies separate capital deepening into IT-capital deepening and all other forms of capital deepening. In all three cases IT-capital is defined as computer hardware, software, and communications equipment. The two academic studies disaggregate TFP into IT-producing and non-IT-producing sectors.

The results of these studies reveals that IT-related capital deepening contributed between one-third to one-half a percentage point to the acceleration in productivity in the late nineties. This indicates that a large part of why workers became more productive after 1995 is that they had more high-technology equipment with which to perform their jobs. Growth in investment in all other forms of capital, machinery, structures, etc., slowed during the late '90s and contributed less to productivity in this period than during the "productivity slowdown". The increase in labor quality was relatively similar across both time periods and thus did not contribute much to the productivity revival. TFP, on the other hand, did accelerate appreciably in the later period, adding between two-thirds to nine-tenths of a percentage point to the relative change in the rate of productivity growth.

It appears, then, that the productivity revival is concentrated in IT-capital deepening and a pickup in TFP. Jorgenson and Stiroh and Oliner and Sichel both find that TFP acceleration in IT-producing industries added about a quarter percentage point to the productivity revival. The increase in TFP in other industries accounted for about a half of a percentage point. This acceleration in TFP in non-IT-producing industries could be due to the use of IT or it could be due to a number of other factors--the coarseness of the growth accounting framework is ill-suited to localize the causes of TFP growth. Among the contributions of IT to TFP, the evidence suggests that it is unlikely that the Internet has yet to contribute substantially to productivity growth. One possible avenue through which the Internet could make the economy more productive is through the cost efficiencies attained through business-to-business e-commerce. Nevertheless the magnitude of these transactions has not been large enough to have much impact on the aggregate numbers. It is possible that valuing the services provided by the Internet as a final, consumer good has suffered from the measurement issues discussed above, in which case the Internet has made some very modest contribution to productivity.[7]

The results of both these studies suggest that the productivity acceleration was not entirely due to higher productivity in the manufacture of semiconductors and other IT equipment. Rather, these industries probably contributed around one quarter of the one percentage point difference between productivity growth during 1973-1995 versus productivity growth during 1995-1999. By identifying IT-capital deepening, these studies also put a lower bound on the contribution from the use of IT of around one-third of a percentage point. The contribution from IT use could be even greater if some or all of the increase in TFP in non-IT-producing industries can be attributed to IT use.

[7] Oliner and Sichel review some of the literature on e-commerce.

IV. OTHER ANALYSES

Growth accounting is a blunt tool that can leave many questions answered unsatisfactorily.[8] In order to get a better idea of how investment in IT has affected productivity, many authors have conducted the analysis at the level of the firm or the industry.

Two studies which are representative of this literature are Stiroh (2001) and Brynjolfsson and Hitt (2000). Stiroh's study looks at productivity in the late 90's in 61 different industry groups sorted by level of investment in IT. In order to control for endogeneity, he measures industry IT investment undertaken before 1995.[9] His main finding is that industries that had invested heavily in IT experienced more rapid productivity growth than other industries. This result is consistent with the New Economy story that the increased use of IT is making American business more productive. After comparing industry groups, Stiroh concludes that the aggregate productivity revival is entirely due to industries that produce IT or intensively use IT; industries that do not intensively use IT contributed essentially nothing to the productivity revival. While industry productivity is compared to lagged IT investment for econometric reasons, the incidental finding of this paper is that unlike other forms of capital, outlays for IT affects productivity several years after the investment is made.

In order to estimate the effect of investment in IT on firm productivity, Brynjolfsson and Hitt track the amount of computer investment undertaken by a sample of 600 firms over an eight year period. They find that over the short-term, the marginal cost of computer investment is equal to its marginal revenue--a result that suggests that over the short-term IT investment contributes to productivity solely though the capital deepening mechanism. Interestingly, they find that over the longer-term (seven years) marginal revenue rose to between two to five dollars for every dollar invested in computers. The authors interpret this finding as suggestive evidence of the existence of productive complementarities between computer investment and organizational restructuring.

Both of the above papers uncover evidence that investment in IT affects productivity with a lag of a few years. This finding is consonant with the theory that rapid capital investment entails large "adjustment costs". According to the IT version of this story, adjustment costs are equated with the time and resources spent by employees in learning how to properly utilize the newly available IT capital as well as the time and resources spent in organizational learning as firms reconfigure their operations. Along these lines, several studies have postulated that the productivity slowdown and subsequent revival are intimately linked by adjustment costs. Greenwood and Yorukoglu

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[8] Additionally, traditional growth accounting may impose an undesirable degree of structure to generate results, including a homogeneous of degree one aggregate production function and perfectly competitive markets.

[9] It is very plausible that industry productivity is contemporaneously correlated with IT investment--industries that experience faster productivity growth could be expected to then invest more heavily in IT. Ignoring this factor would produce inconsistent estimates of the impact of IT on productivity.

(1997) claim that investment in IT, which experienced rapid growth in 1970's *caused* the productivity slowdown as unmeasured adjustment costs made output growth look artificially small. The productivity revival, they claim, represents the efficiency gains from IT investment finally outpacing the associated adjustment costs. This theory would seem to provide a direct reply to the 'Solow paradox'. Writing in 1987, Robert Solow famously remarked "We see the computer age everywhere except in the productivity statistics." According to the adjustment cost view, the slow growth in productivity experienced at the time of Solow's remark reflect the large unmeasured costs of adapting to the computer age during the 1970's and 1980's--costs that were finally outweighed by the benefits by the late 1990's.[10]

The finding that IT investment affects productivity with a lag would seem to bode well for future productivity growth. Aggregate investment in IT continued at a brisk pace well into the late 1990's. If the pattern of lagged dependence of productivity on IT continues, we could expect productivity to continue its healthy growth. Caution, however, is warranted when predicting productivity numbers. As Taylor (2001) observes,

> From a macroeconomic perspective the New Economy isn't really new. After all, productivity growth rates averaged about 3.0 percent per year in the 1950' and 1960's. …But the stagflation of the 1970's--resulting from a combination of unlucky economic events and ill-conceived public policy--arrived nonetheless.

It is sometimes said that from an economic perspective technological progress is like manna from heaven, a gift whose source is not well understood. Because of this, it is unlikely that a policymaker can affect the arrival rate of this gift in the short run. Public policy can, however, create an environment that allows society to fully capture the benefits of technological advancements. The rapid pace of change in the high tech sector requires labor and capital markets that are fluid and dynamic. Excessive regulation could harm the ability of industry to quickly and effectively respond to new opportunities opened up by technological breakthroughs. Moreover, the inherent volatility of enterprise in a sector of the economy undergoing rapid technological change demands a tax structure that creates the appropriate incentives for entrepreneurs and investors to accept this added risk. The likely existence of "spillover effects" from the development of IT implies that the benefits from entrepreneurial activity in this sector flow throughout the economy. Thus, creating incentives for IT entrepreneurial activity is akin to encouraging the private provision of a public good.

V. CONCLUSION

A consensus has emerged regarding the acceleration in productivity that occurred in the late 1990's. Two points that have found widespread agreement are:

[10] Along similar lines, in 1990 Paul David drew on the historical parallels to note that "In 1900, contemporary observers well might have remarked that the electric dynamos were to be seen 'everywhere but in the productivity statistics'!"

- Information technology contributed significantly to the productivity revival. At least half of the one-percentage point increase in labor productivity growth is attributable to IT. In all likelihood the contribution from IT is even greater than this conservative estimate.
- Both the production and use of IT has had an impact on the productivity revival.

These results imply that the New Economy thesis, when applied to the historical experience, has a sound empirical foundation.

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