Comments Welcome

Are ICT Spillovers Driving the New Economy?

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Abstract

Some observers have raised the possibility that production spillovers and network effects associated with information and communications technology (ICT) are an important part of the "New Economy." Across U.S. manufacturing industries, however, ICT capital appears correlated with the acceleration of average labor productivity (ALP) growth as predicted by a standard growth model, but not with total factor productivity (TFP) growth as these New Economy forces imply. Once one allows for productivity differences across industries, measured TFP growth is uncorrelated with all capital inputs, including ICT capital. This provides little evidence for a New Economy story of ICT-related spillovers or network effects driving TFP growth throughout U.S. manufacturing.

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I. Introduction

The resurgence of U.S. average labor productivity (ALP) growth in the late 1990s has generated considerable attention with many studies reporting a substantial impact from both the production and the use of information and communications technology (ICT).[1] The ALP revival is also a key piece of evidence for those touting a "New Economy" in the U.S.[2] Strong ALP growth, however, easily fits within a traditional "Old Economy" framework that includes technological progress, price-induced input substitution, and capital deepening, and thus does not necessarily imply fundamentally new economic forces.

The U.S. economy also enjoyed a resurgence of measured total factor productivity (TFP) growth, however, which has received considerably less attention and is much more in the spirit of the New Economy. While some of the TFP acceleration reflects technological progress in ICT-producing industries, TFP gains appear widespread. This TFP revival opens the possibility that New Economy forces like ICT-related spillovers or network effects are contributing to economy-wide TFP growth. This would imply that standard measurement tools are failing to capture a substantial portion of the economic impact from ICT-use.

This paper examines TFP growth in U.S. manufacturing industries to address one specific question: Are measured TFP gains linked to ICT-use? Neoclassical theory predicts that ICT-use should not cause TFP growth. The rapid decline in quality-adjusted ICT prices leads to traditional effects of investment, input substitution, and capital deepening. This "pecuniary externality" contributes directly to output and ALP growth, but not TFP growth. ICT-related production spillovers or network effects, however, could also yield a "non-pecuniary externality" that pushes the growth contribution of ICT beyond the neoclassical baseline.[3] In this case, ICT investment would also lead to TFP growth. This paper provides a first step in the search for these types of non-traditional effects.

I begin by outlining the neoclassical framework and discussing five channels – production spillovers and network externalities, input measurement error, omitted variables, reverse causality, and increasing returns – that could lead to an observed correlation between ICT capital and measured TFP growth. While these factors are not always conceptually distinct, they allow the possibility that the

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[1]For example, Bureau of Labor Statistics (BLS, 2000), the Council of Economic Advisors (CEA, 2001), Jorgenson and Stiroh (2000), and Oliner and Sichel (2000. Following the U.S. reclassification of software as an investment good in 1999, I define ICT capital to include computer hardware, computer software, and telecommunications equipment.
[2]Stiroh (1999) reviews the new economy literature.
[3]OECD (2000a, 2000b), Schreyer (2000), and van Ark (2000) raise the possibility of this channel. See Griliches (1992) for a discussion of pecuniary and non-pecuniary externalities.

neoclassical framework employed in earlier studies is inappropriate for measuring the economic impact of ICT.

To search for these effects, I compare ICT capital to output, ALP, and TFP growth. If ICT capital is approximately described as a neoclassical input, there will be a positive link with output and ALP growth, but not with measured TFP growth. If there is something special about ICT capital that is missed in conventional growth accounting estimates of TFP, then one would also expect a link with measured TFP growth. To test this, I use productivity data for U.S. manufacturing industries from 1973 to 1999 to look for correlations between ICT capital intensity and TFP growth.

The data show a link between ICT capital deepening and ALP growth – U.S. manufacturing industries that invested heavily in ICT in the late 1980s and early 1990s show stronger ALP gains in the late 1990s. In terms of TFP growth, however, the relationship is weaker. After removing the ICT-producing industries, the acceleration of TFP growth for ICT-intensive industries is larger, but not significantly different from other industries. This suggests the primary impact of ICT is through traditional capital deepening channels and provides little evidence that ICT investment also generates measured TFP growth.

A second set of results compares output and measured TFP growth to the growth in all production inputs and leads to three conclusions. First, there is substantial variation in the productive impact of different types of ICT capital. Telecommunications equipment, for example, consistently shows a *negative* coefficient in the output and TFP regressions. This could reflect large adjustment costs associated with implementing this type of capital. Second, it is critical to account for heterogeneity across industries when analyzing ICT and productivity linkages. In particular, the two industries that produce ICT hardware and equipment show much faster productivity growth than other industries and one can draw incorrect inferences if these differences are ignored. Finally, once one accounts for this heterogeneity, TFP growth appears uncorrelated with input growth, suggesting that the neoclassical view of exogenous TFP growth is approximately correct.

These results provide little obvious evidence for a "New Economy" view of large ICT-related production spillovers or network effects that generate TFP growth. Of course, this lack of evidence does not eliminate the possibility that non-traditional ICT effects exist. Integration of computing and communications equipment is still relatively new and manufacturing industries are not the most intensive users of ICT, for example, so these effects may still be found. More evidence is needed, however, before the New Economy view of production spillovers and network effects replaces the neoclassical view of input substitution and capital deepening.

II. Estimating the Impact of ICT Capital

This section describes the basic neoclassical model of production and how it is has been used to quantify the impact of information and communications technology (ICT) in a traditional neoclassical framework. I then discuss alternative effects that move beyond the neoclassical model. ICT capital, for example, could generate a production spillover that raises the marginal product above marginal cost in another firm. Alternatively, economists could mismeasure ICT capital or ICT capital could be correlated with omitted inputs. In any of these cases, there would be a positive correlation between ICT capital accumulation and measured TFP growth that is not predicted by the neoclassical model.[4]

(a) ICT in a Neoclassical Model

The standard neoclassical model is well known and has been used extensively to evaluate to examine the link between ICT and productivity. BLS (2000), CEA (2001), Jorgenson and Stiroh (1999, 2000), Oliner and Sichel (2000) employ it at the macro level; Berndt and Morrison (1995), Brynjolfsson and Hitt (1995), Gera et al. (1999), Lichtenberg (1995), Lehr and Lichtenberg (1999), McGuckin and Stiroh (2000a, 2000b), Steindel (1992), and Stiroh (1998, 2001) provide results from an industry or firm perspective.

For industry analysis, I begin with a gross output production function that relates output to primary inputs (capital and labor), intermediate inputs (goods and services purchased from other industries), and TFP as:

$$(1) \qquad Y_i = Z_i \;\; f_i(K_{i,ICT}, K_{i,O}, H_i, M_i)$$

where Y is real gross output, K_{ICT} is ICT-related capital, K_O is other forms of capital, H is hours worked, M is intermediate inputs, and Z is a Hicks-neutral total factor productivity index that shifts the production function, all for industry *i*. Time subscripts have been suppressed.[5]

Taking logs of all variables and differentiating Equation (1) with respect to time gives:

$$(2) \qquad d\ln Y = e_{ICT}\, d\ln K_{ICT} + e_O\, d\ln K_O + e_H\, d\ln H + e_M\, d\ln M + d\ln Z^T$$

where ε represents the output elasticity of each input and $d\ln Z^T$ is *true* TFP growth. Note that constant returns to scale is not imposed here.

Solow (1957) showed how the neoclassical assumptions of competitive input markets (each input is paid it marginal product) and input exhaustion (all revenue is paid to factors) lead to the

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[4]Of course, one could observe a negative correlation which might imply adjustment costs as suggested by Kiley (1999, 2000).

[5]This simple representation ignores utilization issues, adjustment costs, and labor quality effects. Basu et al. (2000) present a more developed production function.

equilibrium condition that an input's factor share (α) equals its output elasticity (ε).[6] For example, for ICT capital:

$$(3) \qquad \varepsilon_{ICT} \equiv \frac{\partial Y}{\partial K_{ICT}} \frac{K_{ICT}}{Y} = \frac{P_{K,ICT} K_{ICT}}{Y} \equiv \alpha_{ICT}$$

where $P_{K,ICT}$ is the rental price of ICT capital and output prices have been normalized to one.

In the case of ICT, particularly computer hardware, rapid technological progress in ICT-production gives rise to a "pecuniary externality" in the form of rapidly falling ICT prices. This provides strong incentives for firms to invest in ICT. In addition, ICT rental prices are dominated by rapid depreciation and capital losses, which raise the rental cost of ICT relative to other assets and raises the ICT input share. Thus, ICT capital must have large marginal products to cover the high rental prices.[7]

An important point about this framework is that there is no special role for ICT capital. Economists have long recognized that technological advance differs across industries, which can lead to relative price changes, and that firms substitute between production inputs in response to these changes. Rapid accumulation of ICT equipment can be explained as the profit-maximizing response to falling prices and high marginal products for ICT equipment.

The neoclassical assumptions in Equation (3) hold for all inputs and justify the well-known growth accounting approach.[8] The key insight there is that an input's elasticity is not directly observable, but the neoclassical assumptions allow one to use factor shares as proxies. While it is not always easy to estimate factor shares, particularly for capital, TFP growth can be measured by approximating Equation (2) as:

$$(4) \qquad d\ln Y = \alpha_{ICT} d\ln K_{ICT} + \alpha_O d\ln K_O + \alpha_H d\ln H + \alpha_M d\ln M + d\ln Z^M$$

where the α's represent observed factor shares of the subscripted input, the neoclassical assumptions imply $\alpha_{ICT} + \alpha_O + \alpha_H + \alpha_M = 1$, and $d\ln Z^M$ is *measured* TFP growth under the neoclassical assumptions.[9]

Under the same assumptions, one can rewrite Equation (4) in terms of per hour variables:

$$(5) \quad d\ln ALP = d\ln y = \alpha_{ICT} d\ln k_{ICT} + \alpha_O d\ln k_O + \alpha_M d\ln m + d\ln Z^M$$

where lower-case variables are per hour worked.[10]

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[6]These two assumptions essentially impose constant returns to scale and no profits.
[7]See Jorgenson and Stiroh (1999) for a discussion.
[8]See CEA (2001), Jorgenson and Stiroh (2000), and Oliner and Sichel (2000) for recent examples in the ICT context.
[9]See Diewert (2000) for a broad survey of the difficulties involved in estimating TFP growth.

Equations (4) and (5) can be implemented either as a growth accounting equation (where $d\ln Z^M$ is calculated to make it hold) or as an estimating equation (where $d\ln Z^M$ is estimated econometrically) and shows the direct link between ICT capital and output or labor productivity. Firms or industries that invest heavily in ICT capital will see ICT capital growing faster than labor hours ($d \ln k_{ICT} > 0$). This leads directly to a link with ALP growth that is proportional to ICT's observed input share; this is often called the "ALP contribution of ICT capital."

In this framework, there is no direct impact on TFP growth from capital deepening. TFP growth, by definition, is the output growth that is *not* explained by input growth, so any output contribution associated with ICT investment is attributed to ICT capital deepening and not TFP. As pointed out by Baily and Gordon (1988) "there is no shift in the user firm's production function (pg. 382)" and thus no TFP growth from the use of ICT.[11]

(b) Non-Traditional Effects of ICT

This section considers the relationship between ICT capital and TFP growth in a world where the neoclassical assumptions do not hold. If the neoclassical assumptions fail, then Equations (4) and (5) may be poor approximations to the true productivity relationships.[12] This failure could reflect production spillovers, omitted variables, embodied technological progress, measurement error or reverse causality, all of which could lead to a positive link between TFP growth and ICT intensity.

Without getting into potential explanations for now, consider what happens if the elasticity of ICT exceeds ICT's measured input share, $e_{ICT} > a_{ICT}$. In this case, measured TFP growth (Equations (4)) will be a biased estimate of true TFP growth (Equation (2)). More important, if this is the only error, it implies a direct relationship between ICT capital and measured TFP growth. For example, if $e_{ICT} = a_{ICT} + w$, where w is a wedge between the unobserved elasticity and the observed factor share:

$$(6) \qquad d \ln Z^M = d \ln Z^T + wd \ln K_{ICT}$$

Equation (6) shows that if the elasticity exceeds the factor share for ICT, then conventionally measured TFP growth will be correlated with ICT capital. Thus, failures of the neoclassical framework provide a potential link between ICT capital deepening and measured TFP growth. I now consider various explanations for this type of link.

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[10]This ignores the labor quality or composition effects descried in Jorgenson and Stiroh (2000). This is done here for simplicity and because the BLS data do not include compositional effects at the industry level.
[11]See Stiroh (1998), Jorgenson and Stiroh (1999), and Bosworth and Triplett (2000) for more on this point.

i. Production Spillovers and Network Externalities

The idea that investment might generate external productivity effects goes back at least to the "learning-by-doing" model of Arrow (1962), which include productivity-enhancing experience as a function of the cumulative capital stock. Similarly, DeLong and Summers (1991, 1992, 1993) conclude the social return to equipment exceeds the private return, implying productivity externalities, perhaps through production process efficiency gains, reverse engineering, or organization learning accompanying investment in new equipment.[13] Wolff (1991) reports a statistical link between growth in the capital/labor ratio and TFP growth for seven countries from 1870 to 1979, which he attributes to embodied technical progress, investment-led organizational change, learning-by-doing, technology-induced capital accumulation, and positive feedback effects.[14]

In the specific context of ICT, OECD (2000a, 2000b) discuss potential production spillovers and network effects. For example, OECD (2000a) argues that the emergence of the Internet in the mid-1990s greatly expanded the effectiveness of ICT and may lead to TFP growth. Similarly, OECD (2000b) suggests that improved business-to-business communications, facilitated by ICT, reflect new organizations of production and sales. At a more micro level, Gandal (1994) found evidence that computer spreadsheet users benefit from network externalities as firms gain from the ability to transfer information between users. Similarly, Brynjolfsson and Kemerer (1996) reported potential network effects in software, where the value to a user may rise due to network externalities from a community of users. Thus, one firm's ICT investment could increase the productivity of others, a classic spillover effect that would raise measured TFP growth.

Alternatively, the marginal product of capital could exceed the marginal cost as firms receive benefits beyond what the market forces them to pay. van Ark (2000) raises this possibility in the context of ICT. In an early example, Bresnahan (1986) reports evidence of "downstream spillovers," which he interprets as a productivity spillover from the firm's computer investment.

These types of "non-pecuniary externalities" in the form of production spillovers and network effects could lead the elasticity of ICT to exceed its measured input share and thus generate a correlation between ICT and measured TFP growth. Evidence, however, has been mixed. Griliches

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[12]Hall (1988, 1990), for example, argued that imperfect competition was a better description of U.S. industries and relaxed these assumptions. More recently, Basu and Fernald (1995, 1997) have shown how the presence of imperfect competition generates misleading inferences about returns to scale.

[13]The DeLong and Summers results have received considerable scrutiny, e.g., Abel (1992), Auerbach et al. (1994), and Mankiw (1995) discuss the results.

[14]It is not clear, however, that this is the type of production spillover that the New Economy proponents have in mind. In the learning-by-doing case, aggregate investment raises the productivity of all firms as the stock of knowledge increases, while the DeLong and Summers result are about production externalities where returns to investment spill over to others. Nonetheless, one could argue that there are spillovers between firms within the same industry, so that one might expect a correlation between industry ICT investment and TFP growth.

and Siegel (1991) find a correlation between computer investment and TFP growth for 4-digit U.S. manufacturing industries, while Stiroh (1998) reports no evidence of a correlation between growth in computer hardware and TFP in U.S. industries. In a cross-section of U.S. firms, Brynjolfsson and Hitt (2000a) finds that the computers' contribution equals its share in short differences, but greatly exceeds it in longer differences. Schreyer (2000) reports little obvious evidence for a link between ICT capital and TFP growth for the G7 countries, although his data end in 1996 and he does not present a rigorous statistical analysis. OECD (2000b) conclude that the available data do not allow clear tests for spillover effects in ICT-using sectors.

ii. Measurement Errors

An alternative explanation is that ICT capital is simply not well measured. At least since Jorgenson and Griliches (1967), economists have known that mismeasured production inputs lead directly to mismeasured TFP growth; if input growth is understated (overstated), measured TFP growth is overstated (understated). This insight has led to considerable effort to correctly measure production inputs and yield better estimates of TFP growth.[15]

In the case of ICT capital, this measurement problem may be particularly difficult, although it is not clear in which direction they run. ICT capital has experienced enormous quality improvements across subsequent vintages, which are accounted for by quality-adjusted price indexes that translate better quality into more quality-adjusted units. The U.S. statistical agencies have expended considerable resources on getting these prices right, but the possibility of systematic error remains. For example, only a small part of software and telecommunication equipment is currently deflated with constant-quality deflators, which suggests a potential understatement of ICT capital and overstatement of TFP growth. This would lead to a positive correlation of measured ICT capital and measured TFP growth. Alternatively, the rapid increase in computing power implied by the hedonic deflators may overstate the amount of computing power actually used, e.g., the large increases in measured capacity could be largely unutilized. Thus, ICT hardware may be overstated and TFP understated.

Potential measurement error also clouds the interpretation of production spillovers. Bresnahan (1986), for example, argues that computer services provided a downstream spillover since the prices did not reflect the true value. In the context of research and development spillovers, however, Griliches (1995) cautions that much of claimed production spillovers in the research and development literature are “not real knowledge spillovers. They are just consequences of conventional measurement problems (pg. 66).” The same caveat applies to ICT spillovers, and it seems very difficult to disentangle production spillovers from measurement error.

iii. Omitted Variables

A third potential failure of the neoclassical model is omitted variables, which is really a specific type of measurement error. The productive impact of any excluded input ends up in the measured TFP residual and moves it further from true TFP growth. In the specific context of ICT, anything that raises productivity, is correlated with ICT-use, and is not measured by the econometrician would lead to a correlation between measured TFP growth and ICT investment.

Brynjolfsson and Hitt (2000b), for example, conclude that firm-level studies typically find ICT elasticities above input shares because “they neglect the role of unmeasured complementary investments (pg. 33).” The excess returns to ICT that were found in some studies, e.g., Brynjolfsson and Hitt (1995), Lichtenberg (1995), Lehr and Lichtenberg (1999), likely reflect returns to omitted inputs.

Examples of this type of omitted variable include organizational change, workplace practices, human capital accumulation and labor quality effects, or research and development effects. As examples of organizational change, Brynjolfsson and Hitt (2000b) discuss the impact of reduced communications costs, flexible jobs, outsourcing, concurrent reengineering, and just-in-time inventory control. Bresnahan, Brynjolfsson and Hitt (1999) point to skill upgrades, education, and increased worker autonomy as factors that interact to raise the value of ICT. In a survey of U.S. establishments, Black and Lynch (2001) find productivity gains associated with a host of workplace practices including profit-sharing plans and employee voice in decision-making. If these changes are correlated with ICT investment but unmeasured in the industry-level data, then one would find a correlation between ICT and measured TFP growth.

iv. Reverse Causality

The standard neoclassical model assumes that TFP growth is an exogenous force that shifts the production function. Hulten (1979), however, has pointed out that much of observed capital accumulation is induced by TFP growth, while real business cycle models routinely allow productivity shocks to affect input accumulation. A similar point has been made in the econometrics literature

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[15]This focuses on input measurement problems, but there are also potential output measurement problems. The most intensive users of ICT in the U.S. are found in the services and finance, insurance, and real estate industries (Stiroh (1998) and Triplett (1999)). Output, however, is very hard to measure in these industries, so the contribution from ICT may be difficult to ascertain. See Dean (1999) for a discussion of output measurement problems and Diewert and Fox (1999) for a discussion related to ICT.

where the endogeneity of input choices is well known. That is, firms respond to productivity to shocks by increasing inputs since marginal products have risen. This reverse causality story could lead to a correlation between input accumulation and TFP growth.[16]

In principle, one can correct for this endogeneity problem with instrumental variable techniques or be comparing TFP growth to lagged ICT intensity. While it is difficult to obtain suitable instruments, this is a practical not a conceptual concern. Moreover, a link from TFP growth to ICT capital does not seem to be what the New Economy literature has in mind regarding potential links. Rather, the discussions of ICT spillovers argue that the causality runs from ICT capital to measured TFP growth.

v. Increasing Returns and Imperfect Competition

Finally, measured TFP growth is typically estimated under the maintained assumptions of constant returns to scale and perfect competition. Building on the work of Hall (1988, 1990), Basu and Fernald (1995, 1997) have shown that allowing for non-constant returns and mark-ups (as in the case of imperfect competition) is important. For example, if markups exist so price exceeds marginal cost, elasticities will typically exceed revenue shares. In this case, measured TFP growth will be too high, since the estimated contribution of inputs is too low. In principle, this could lead to a correlation between ICT and measured TFP growth, but this is not necessarily an ICT issue and would affect all inputs.

(c) Discussion of the Competing Views

There is evidence for some type of failure of the neoclassical model, e.g., the papers surveyed by Brynjolfsson and Hitt (2000b) that find excess returns, omitted variables, or a correlation between TFP and ICT growth at the firm level. The next issue is whether the potential explanations discussed above are indeed fundamentally different from each other, and whether they can be sorted out empirically. It seems that both practical and conceptual arguments point to broadly defined measurement error – including mismeasured inputs and omitted variables – as the most likely explanation.

ICT capital goods are experiencing enormous quality improvements, which makes it quite difficult to measure them on an accurate and consistent basis. While the U.S. statistical agencies have incorporated hedonic, matched model, and other statistical methods to capture these quality changes, it remains unclear how accurate this has been. In addition, many of the micro factors that have been found to be important, e.g., organizational change or workplace practices, are quite difficult to measure at the industry-level and thus may introduce an omitted variable bias. Finally, the most

[16] See Griliches and Mairesse (1998) for an econometric discussion.

intensive users of ICT are in services and finance-related industries, where output is notoriously hard to measure. Measurement problems seem to be built into the ICT debate.

Moreover, on a conceptual level, it is not clear what production spillovers really are. Of the five factors discussed by Wolff (1991) to explain the aggregate capital deepening/TFP link, only learning-by-doing and positive feedback effects seem to be true production spillovers. Investment-led organizational changes suggest an omitted input; technology-induced capital accumulation explains the correlation but has the causality reversed; and embodied technical change can be thought of as a type of measurement error.[17] As Griliches (1992, 1995) argued in the context of research and development spillovers, it is very difficult to differentiate measurement errors from true productivity spillovers.

While sorting out these different explanations is an important task, this paper only takes the necessary first step and searches for empirical links between between ICT capital accumulation and measured TFP growth.

III. Data and Summary Statistics

Data are from the BLS multifactor productivity database for manufacturing industries. The focus on manufacturing reflects the limited availability of TFP estimates for other industries. Jorgenson and Stiroh (2000) report TFP estimates for all broad sectors, but the non-manufacturing sectors are defined quite broadly and end in 1996. Using manufacturing data, however, has both advantages and disadvantages. On one hand, most of ICT investment is in non-manufacturing industries, particularly services, FIRE, and trade, so the biggest impact from ICT may be missed. On the other hand, it is generally thought that output, and therefore productivity, is better measured in manufacturing, so output mismeasurement problems should be less of a concern with this data.

The latest data are from BLS (2001) and methodological details are in BLS (1997). These data contain information on gross output, primary inputs (capital and labor), and intermediate inputs (purchased materials, energy, and business services), and are available for all private industries, manufacturing as a whole, durable manufacturing, nondurable manufacturing, and most two-digit manufacturing industries from 1948-1999.[18]

BLS calculates TFP growth in the standard growth accounting way, i.e., growth of gross output less the two-period, share-weighted growth rates of inputs. For estimates of output for individual manufacturing industries, BLS excludes transactions within the specific industry, while

[17]If hedonic deflators accurately captured all characteristics of an investment good, all vintages would be measured in equivalent, constant-quality efficiency units and embodiment would not exist.

[18]TFP estimates are not published by BLS for Tobacco (SIC # 21) and Leather (SIC #31) because of the small industry size and data limitations, so I do not include them here.

aggregate manufacturing excludes sales between all industries. The only measure of labor input for the two-digit industries is hours worked, so there are no labor quality/composition effects. I emphasize that I use the official BLS estimates of TFP for each industry.

BLS estimates real productive capital stocks for individual assets using a perpetual inventory method with hyperbolic age/efficiency profiles for each asset. Individual productive capital stocks are aggregated into a measure of real capital input using a traditional Hall-Jorgenson user cost formula that accounts for price deflators, depreciation rates, and tax parameters. The value of capital income reflects the user cost and the productive capital stock.

BLS now provides details on capital services for various "information capital" assets. In particular, data on real capital input and the value of capital income are available for computer hardware, computer software, telecommunications equipment, and other office and accounting equipment, as well as an aggregate of the four components. In this paper, I define ICT to include computer hardware, computer software, and telecommunications equipment and create an index called "ICT Capital Input" using a standard Tornqvist index. All other assets, including land and inventories, are combined into "Other Capital Input." I also combine computer hardware and software into a single index of "Computer Capital Input." Note that this level of ICT aggregation reflects the most detailed data available from BLS.

Table 1 shows summary statistics about the size of the industry and ICT intensity for all private business, nonfarm business, manufacturing as a whole, and the component manufacturing industries. Gross output is measured in current dollars and shows a range from $49 billion for Miscellaneous Manufacturing to $498 billion for Motor Vehicle and Equipment in 1999. In terms of ICT intensity, measured as the nominal ICT share of total capital services, manufacturing is less ICT-intensive than the economy as a whole (11.5% vs. 16.1%), which reflects the rapid ICT investment in services, trade, and finance industries. The ICT capital shares also vary widely ranging from only 2.6% for Petroleum and Coal Products to 32.4% in Industrial Machinery and Equipment in 1999.

Table 2 reports average ALP and TFP growth rates for two periods – 1984-93 and 1993-99. These periods will be the main periods of comparison and were chosen for the following reason. Productivity is pro-cyclical and rises after recessions, so 1984 was chosen to avoid the productivity slowdown and cyclical recovery that accompanied the recessions of 1980 and 1981-82. 1993 was chosen since econometric tests point to a structural break in the manufacturing ALP series in the third quarter of 1993.[19] Other comparisons begin in 1973, the conventional starting point of the aggregate U.S. productivity slowdown.

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[19]See Stiroh (2001) for details.

The data show a substantial pickup in both ALP and TFP growth when 1984-93 is compared to 1993-99.[20] This acceleration is not limited to a few industries, e.g., the median change was 0.8% for ALP growth and 0.3% for TFP growth. There is also considerable variation with several industries showing a slowdown in both ALP and TFP growth (Primary Metal Industries, and Instruments and Related Products) and others showing large pickups (Industrial Machinery and Equipment, and Electronic and Other Electric Equipment).

As a final point, it is worthwhile to identify the two manufacturing industries that actually produce ICT equipment, Industrial Machinery and Equipment (SIC #35) and Electronic and Other Electric Equipment (SIC #36). SIC #35 includes production of computer hardware, as well as various machine tools, construction equipment, and special industry machines, while SIC #36 includes production of telecommunications equipment and semiconductors, as well as electric motors, household appliances, and lighting equipment. Since the production of ICT has benefited substantially from fundamental technological gains and shows extraordinary measured productivity growth, the econometric work will be careful to see if these two industries are driving the results.

IV. Empirical Results

The econometric work consists of three parts. The first uses a difference in difference estimator to compare the relative ALP and TFP gains for ICT-intensive industries to other industries. This follows McGuckin and Stiroh (1998, 2000a) and Stiroh (2001). The second estimates standard production functions that compare output growth to input growth. This section also compares TFP growth to input growth to look for New Economy effects like production spillovers or network effects. A correlation between ICT capital and TFP growth would be consistent with the existence of these forces, but it is obviously not sufficient due to the other potential explanations discussed above. The third provides robustness tests for the production function and TFP regression estimates.

(a) Difference in Difference Results

Before proceeding with the difference in difference results, it is useful to examine a simple plot of TFP acceleration and ICT intensity. Chart 1 compares the acceleration of TFP growth from 1984-93 to 1993-99 to 1993 ICT capital intensity, measured as the nominal share of ICT capital income in total capital income. Using all industries, there seems to be a strong relationship (the steep line). The two ICT-producing industries (SIC #35 and #36) are productivity outliers and when they are excluded, there is no relationship (the flat line). If the two industries with high ICT capital shares but little TFP acceleration, Instruments (SIC #38) and Printing and Publishing (SIC #37), are also

[20] Note that the pickup for private industries is much smaller than for manufacturing. This reflects the fact that the acceleration in economy-wide productivity began later than in manufacturing (1995 vs. 1993).

excluded, there appears to be some positive relationship. Overall, this does not suggest a robust and pervasive link.[21]

A more formal way to get at this is with a difference in difference style regression:

$$X_{i,t} = a + bD + gI + dD \cdot I + e_{i,t},$$
$$(7) \qquad D = 1 \; if \; t \geq 1994, \; D = 0 \; otherwise$$
$$I = 1 \; if \; ICT - intensive, \; C = 0 \; otherwise$$

where α is the mean growth rate for non ICT-intensive industries in the period prior to 1994, α+γ is the mean growth rate for ICT-intensive industries prior to 1994, β is the acceleration for non-ICT intensive industries, β+δ is the acceleration for ICT-intensive industries, and δ is the differential acceleration of ICT-intensive industries relative to others.[22] $X_{i,t}$, the dependent variable, is the annual growth rate of either ALP or TFP.

The regression in Equation 7 addresses a specific question: do ICT-intensive industries, on average, show faster ALP and TFP growth than other industries? In a traditional neoclassical world, one would expect ICT to contribute to ALP growth, but not necessarily to TFP growth. If the neoclassical model fails for any of the reasons described above, however, then there may also be a correlation with TFP growth. Comparing the results from the ALP and TFP regressions gives some insight on the importance of these alternative effects.

I define an ICT-intensive industry as one with an above median value share of ICT capital services in total capital services in 1993; Table 1 identifies these industries. It is important to define the ICT indicator prior to the acceleration period in order to reduce simultaneity bias from demand or productivity shocks that could induce ICT investment. That is, by defining ICT intensity in 1993 and looking at the acceleration of TFP growth after 1993, I can avoid the possible reverse causality arguments that TFP shocks induced ICT investment. If industries were expecting future demand increases and productivity gains, however, this timing convention would be an imperfect approach.

Table 3 reports results.[23] The top panel examines the period 1984-99 and the bottom panel examines a longer period 1973-99. The first columns reports results for the ALP regression with all 18 industries and shows that the productivity acceleration was 2.0 percentage points faster for ICT-

[21]The lines are fitted values from an OLS regression of TFP acceleration on 1993 ICT intensity and a constant. The slope is 0.069 (p-value = 0.13, R^2=0.13) when all 18 industries are used and the slope is 0.008 (p-value = 0.80, R^2=0.01) when SIC #35 and #36 are excluded. When the two other outlier industries, Printing and Publishing and Instruments, are also excluded the slope is 0.212 (p-value = 0.063 and R^2=0.26).

[22]It is important to look at relative TFP growth in order to control for common shocks that affect measured TFP growth for all industries, i.e., it is well known that both ALP and TFP are procyclical, so one must worry about business cycle effects.

intensive industries when 1993-99 is compared to 1984-93 and 2.5 percentage points when 1993-99 is compared to 1973-93.

As suggested by Chart 1, however, the ICT-producing industries (SIC #35 and SIC #36) are somewhat different and the second column drops these two industries. The results still show a sizable ALP acceleration of 1.1 and 1.3 percentage points that is significant at the 10% level. This result is weaker statistically, but an increase in average ALP growth of over 1 percentage point is quite large economically.

The next two columns report estimates of similar regressions, but now with measured TFP growth as the dependent variable. If ICT spillovers, network effects, or measurement error are important, one would expect to see a positive estimate of δ in Equation (7). When all manufacturing industries are included, the data show a large and significant difference in the acceleration of TFP growth for the ICT-intensive industries, 1.1 percentage point in the top panel and 1.4 in the bottom. Once the ICT-producing industries are dropped, however, the size of the coefficient drops substantially and it is no longer significant. Combining the time dummy coefficient and the interaction term shows that the ICT-intensive industries do show a significant acceleration of TFP growth, but it is not significantly different from the other industries.

These results indicate a relatively large acceleration in ALP growth for the ICT-intensive industries, but there is less evidence of relative gains in TFP growth. There does seem to have been a difference in the acceleration of TFP for the ICT-intensive industries in the late 1990s, but the data cannot reject the null hypothesis that the ICT intensive industries show the same TFP gains as other industries. While this is a relatively tough test that asks a lot of the available data, the results seem broadly consistent with the neoclassical model. Two caveats deserve mention, however. First, this specification is relatively restrictive and puts all of the explanatory burden on a single ICT capital share; the next section addresses this issue. Second, due to data limitations, this analysis is restricted to manufacturing industries, which are not as ICT-intensive as many services, trade, and finance industries. Nonetheless, these results do not provide obvious evidence that ICT capital intensity is correlated with TFP gains.

(b) Production Function Style Regressions

This section extends the earlier results by examining the link between output and ICT capital and between TFP and ICT capital. I begin with a production function regression that decomposes capital into ICT and other capital. I then further decompose ICT into computers (hardware and

[23] All standard errors are corrected for heteroskedasticity and are corrected to allow for correlations of residuals over time for each industry by using the product of the actual residuals. This clustering correction tends to

software) and telecommunications equipment components.[24] As above, I then use the same explanatory variables in a regression with TFP as the dependent variable to search for evidence of non-traditional effects.

As is standard, I begin with a Cobb-Douglas form for Equation (1):

$$(8) \qquad Y_{i,t} = A_i e^{f(t)} K_{ICT,i,t}^{\beta_{ICT}} K_{N,i,t}^{\beta_N} H_{i,t}^{\beta_H} M_{i,t}^{\beta_M} e^{\varepsilon_{i,t}}$$

where A_i is an industry-specific productivity level effect that grows according to a common path *f(t)*, β is the elasticity of the subscripted variable, and $e_{i,t}$ are serially uncorrelated random errors for each industry.

This implies a standard form for a production function regression:

$$(9) \qquad \ln Y_{i,t} = \beta_{ICT} \ln K_{ICT,i,t} + \beta_N \ln K_{N,i,t} + \beta_H \ln H_{i,t} + \beta_M \ln M_{i,t} + f(t) + \mu_i + \varepsilon_{i,t}$$

where μ_i are a set of industry-specific effects.

To remove the industry-specific effect, first-difference Equation (9) and estimate the following regression:

$$(10) \qquad d\ln Y_{i,t} = \beta_{ICT} d\ln K_{ICT,i,t} + \beta_N d\ln K_{N,i,t} + \beta_H d\ln H_{i,t} + \beta_M d\ln M_{i,t} + \lambda_t + \nu_{i,t}$$

where λ_t are year dummy variables to capture common shocks and $\nu_{i,t}$ is the differenced residual.

If one believes that input choices are made prior to the realization of the productivity shocks, then Equation (10) can be estimated by ordinary least squares (OLS). It is more reasonable, however, to assume that input choices are correlated with productivity shocks so that one would want to use an instrumental variable (IV) approach. Since IV estimates can be quite dependent on the instrument set, I report both OLS and IV estimates, where the instrument set includes one and two period lags of all independent variables and time dummy variables.[25]

The top panel of Table 4 reports estimates of Equation (10) for a panel of 18 industries for 1984-99. The OLS and IV results in Columns 1 and 3 show a surprising result that ICT capital has a negative and significant coefficient. Hours and intermediate inputs are near their factor shares, as implied by the production function model, and the other capital coefficient is perhaps too large. The data cannot reject constant returns to scale, i.e., sum of coefficients equals one.

Taken literally, the negative ICT coefficient implies that ICT capital is unproductive, which is quite surprising and warrants further attention. Moreover, these results counter other recent studies that typically found a positive link, e.g., the papers surveyed by Brynjolfsson and Hitt (2000b), Lehr

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increase the size of the standard errors.

[24] I don't break out computer hardware from software since they are so highly correlated across.

[25] See Griliches and Mairesse (1999) for details on this identification issue. An alternative instrument set that consisted of demand variables from Basu et al. (2000) produced unreliable estimates and are not reported. An alternative approach based on Arellano and Bond (1991) gave results similar to those reported, although they were quite sensitive to the choice of instrument lag structure and are thus not reported.

and Lictenberg (1999), Licht and Moch (1999), McGuckin and Stiroh (2000b), and Stiroh (2001). This could reflect the focus on manufacturing industries or the broader definition of ICT that includes telecommunications equipment, which was typically not included in earlier studies. Alternatively, this could reflect some type of adjustment cost that temporarily limits the effectiveness of ICT capital, as in Kiley (1999, 2000).

One way to better understand this surprising result is to further decompose ICT capital into computers (hardware and software) and telecommunications equipment components. This regression is reported in Columns 2 (OLS) and 4 (IV), and shows a large negative coefficient on telecommunications equipment and a smaller coefficient on computers. Large variation in the effect of different types of ICT is consistent with the results in Lehr and Lichtenberg (1999) and Licht and Moch (1999), who find that personal computers are particularly productive. Thus, it appears that telecommunications capital is a drag on output, which may explain the difference from earlier studies since they typically focused on computer hardware.

The bottom panel employs the same regression specification, but now uses TFP as the dependent variable. The results again yield a negative coefficient on ICT capital, particularly telecommunications capital. Hours and intermediate inputs are insignificantly different from zero in all specifications, as one would expect in a neoclassical world of exogenous TFP growth and no reverse causality. Other capital, however, has a strong positive coefficient in both the OLS and IV regressions; this implies that other capital has a bigger productive impact than the neoclassical model suggests.

At this point, a second plot helps. Chart 2 plots the average growth rate of TFP growth for 1984-99 across industries against the average growth rate of telecommunications capital for 1984-99. While this is only a partial correlation and endogeneity concerns present any type of structural interpretation, the raw data clearly show a strong negative relationship between TFP growth and telecommunications capital, driven largely by the ICT-producing industries. These industries account for a large part of this relationship (the steep line), although the relationship remains negative and significant when they are excluded (the flat line).[26]

Overall, these results are somewhat mixed. On the positive side, the coefficients on other capital, hours, and intermediate inputs in the output regression are largely reasonable and estimates indicate roughly constant returns to scale. In the TFP regressions, most of the inputs appear

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[26]The lines are fitted values from an OLS regression of TFP growth (annual average for 1984-99) on telecommunications growth (annual average for 1984-99) and a constant. The slope is -0.319 (p-value = 0.00, R^2=0.63) when all 18 industries are used and the slope is -0.13 (p-value = 0.02, R^2=0.33) when SIC #35 and #36 are excluded.

insignificant as expected. These are all reasonable results and suggest that the approach and data are not totally at odds.

On the down side for the New Economy side, ICT capital in general and telecommunications in particular seems to have a negative impact on both output and TFP growth. Others have argued for this type of negative effect from ICT due to large adjustment costs or learning lags, e.g., Kiley (1999, 2000) claims that adjustment costs reduce the productive impact of ICT, but it is useful to explore the data a bit more closely before reaching that conclusion.

Finally, these estimates suggest that, if anything, other capital is associated with a breakdown of the neoclassical model and exhibits large measurement problems or potential spillover effects. A recent study by Joel Popkin and Company (Association for Manufacturing Technology (2000)) reports that improved machine tools have made major contributions to the improved performance of manufacturing, e.g., computer numerically controlled devices are more accurate, more flexible, and involve less set-up costs. If these productive characteristics are not accounted for in the conventional capital estimates, then these productivity gains would show up in the measured TFP residual. More work on the appropriate measurement of these tools is needed.

(c) Robustness Checks

To better understand the results in Table 4, I present robustness checks that change the model specification and estimation technique for both the output and TFP regressions. In all cases, I report results from the broader specification that breaks down ICT capital into the two components and each column uses the same specification for the output regression (top panel) and the TFP regression (bottom panel). Results are in Table 5.

A first potential explanation for the insignificant effect from ICT is simply that there is not enough variation in the data. That is, all results in Table 4 include year dummy variables, which effectively remove the cross-sectional average of each variable in each year so the important upward trends in ICT capital may be soaked up by the year dummy variables. The first column of Table 5 drops the year dummy variables from the OLS regression. For both the output and TFP regressions, the results include a positive although insignificant coefficient on computers while the telecommunications coefficient remains negative and significant. Thus, it appears that time effects are driving some of the results, but the negative effect on telecommunications equipment remains.

A second potential concern is that the results are driven by outliers. One parsimonious way to combat this is to utilize a robust regression technique where observations with large residuals receive relatively small weights. This process is performed iteratively with decreasing weights on large residuals until the estimates converge. The second column shows robust regression results, which do not differ substantially from the earlier estimates. Thus, random outliers are not driving the results.

A third potential concern is that outliers may be more specific. As shown in Table 2, the two ICT-producing industries experienced both ALP and TFP growth that is much faster than other industries. Since the first-difference specification in Equation (10) effectively constrains all industries to experience the same trend effects, i.e., there is a single set of λ_t dummy variables, this could be problematic. A simple way to counter this problem is to include an additional dummy variable in the regression that is set equal to 1 for the two ICT-producing industries (SIC #35 and #36) and set equal to 0 otherwise. The third column reports OLS estimates with this dummy variable and the fourth column reports IV estimates with this dummy variable.

These results with the dummy variable for the ICT-producing industry are more reasonable overall. In the output regressions, the ICT coefficients stay the same sign, but they are smaller and not significant, implying that the ICT impact is not well identified here. The other coefficients are reasonable in size, particularly other capital, and are largely significant. While returns to scale falls, the data do not still reject constant returns. In the TFP regressions, the results are generally insignificant. Other capital is positive and marginally significant in the OLS regression, while telecommunications capital is negative and marginally significant in the IV regression.

One could take the idea that productivity shocks vary across industries even further and allow an industry-specific component in the growth-rate regressions. That is, Equation (8) assumes a common TFP pattern for all industries, which could be relaxed to vary across all industries as:

$$(11) \qquad Y_{i,t} = A_i e^{f_i(t)} K_{ICT,i,t}^{b_{ICT}} K_{N,i,t}^{b_N} H_{i,t}^{b_H} M_{i,t}^{bm} e^{e_{i,t}}$$

where $f_i(t)$ is the industry-specific time path of A_i.

For ease of exposition, assume that TFP growth in each industry differs only by a constant so that $df_i(t) = a_i + l_t$. Taking logs and first differencing Equation (11) yields

$$(12) \qquad \begin{aligned} d\ln Y_i = b_{ICT}\, d\ln K_{ICT,i} + b_N\, d\ln K_{N,i} + \\ b_H\, d\ln H_i + b_M\, d\ln M_i + a_i + l_t + n_{i,t} \end{aligned}$$

where Equation (12) differs from (10) since fixed effect remains in the *first-difference* regression.

The final column of Table 5 reports estimates of Equation (12) for the output and TFP regression. In general, the results are similar to Column 3, suggesting that the ICT-producing industries are the primary source of industry heterogeneity. In terms of output growth, the hours and materials coefficients are well estimated and reasonable, but the other capital coefficient and returns to scale appear small.[27] Computers and telecommunications are negative, although not significant. In terms of TFP, only the intermediate input variable enters with a negative and significant coefficient.

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[27]The low and insignificant capital coefficient and low estimates of returns to scale is a common outcome from fixed effects regressions. See Griliches and Mairesse (1998).

Taken as a whole, these results provide little evidence that broadly defined ICT capital increases measured TFP growth. If anything, the results point to a negative relationship, particularly for telecommunications equipment, although the coefficients do not appear to be estimated very precisely. One explanation is that large adjustment costs reduce the productive impact of ICT investment as firms learn how to implement the latest equipment and reorganize their business process. The bottom line finding is that once one allows for industry heterogeneity, the data seem to lead back to the baseline neoclassical view that TFP growth is essentially an exogenous force that does not result from input accumulation.

V. Conclusions

This paper searches for an empirical link between ICT capital accumulation and measured TFP growth across U.S. manufacturing industries. The results yield three primary conclusions. First, there is little evidence that ICT capital is associated with measured TFP growth, as one would expect in a world with large production spillovers, network effects, or other failures of the neoclassical model. Second, there is considerable variation in the productive impact of computers relative to telecommunications equipment. This suggests some caution when specifying a production function. Finally, it is critical to allow for heterogeneity in productivity shocks across industries. In particular, the two ICT-producing industries have enjoyed quite different productivity experiences in recent years and failure to account for these differences can yield a very misleading picture of the recent productivity experience in U.S. manufacturing.

These estimates are a first step in the search for the non-traditional productivity effects from ICT capital. While the results provide little evidence that these effects are large, several caveats are warranted. This analysis examines only U.S. manufacturing industries, which are not the most ICT-intensive industries. It is possible that different ICT effects are present in other more intensive users of ICT, so work on other industries or countries is needed to corroborate these findings. In addition, some have argued that it is the combination of computing power and communications ability that will eventually transform how business operates. Since the widespread commercialization of the Internet is a fairly recent phenomenon, it is possible that these types of spillover and network gains will eventually be realized after a period of adjustment passes. Given the evidence to date, however, there appears to be no compelling reason to drop the neoclassical framework of technological progress, input substitution, capital deepening in favor of a New Economy explanation of production spillovers and network externalities.

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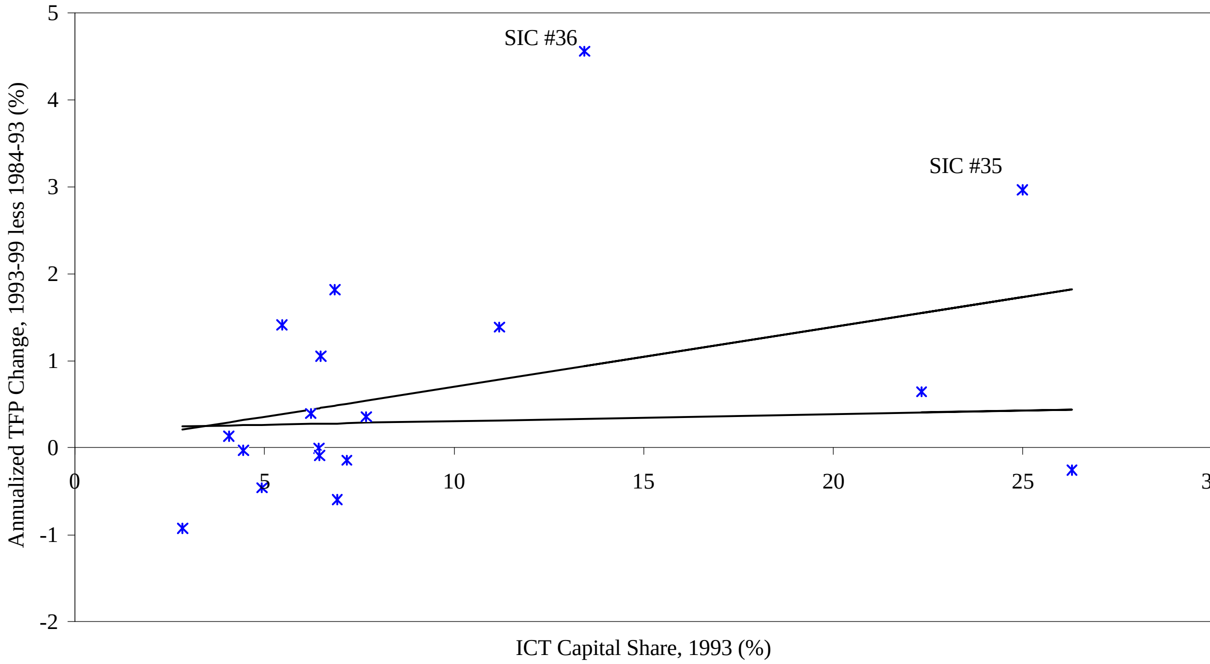
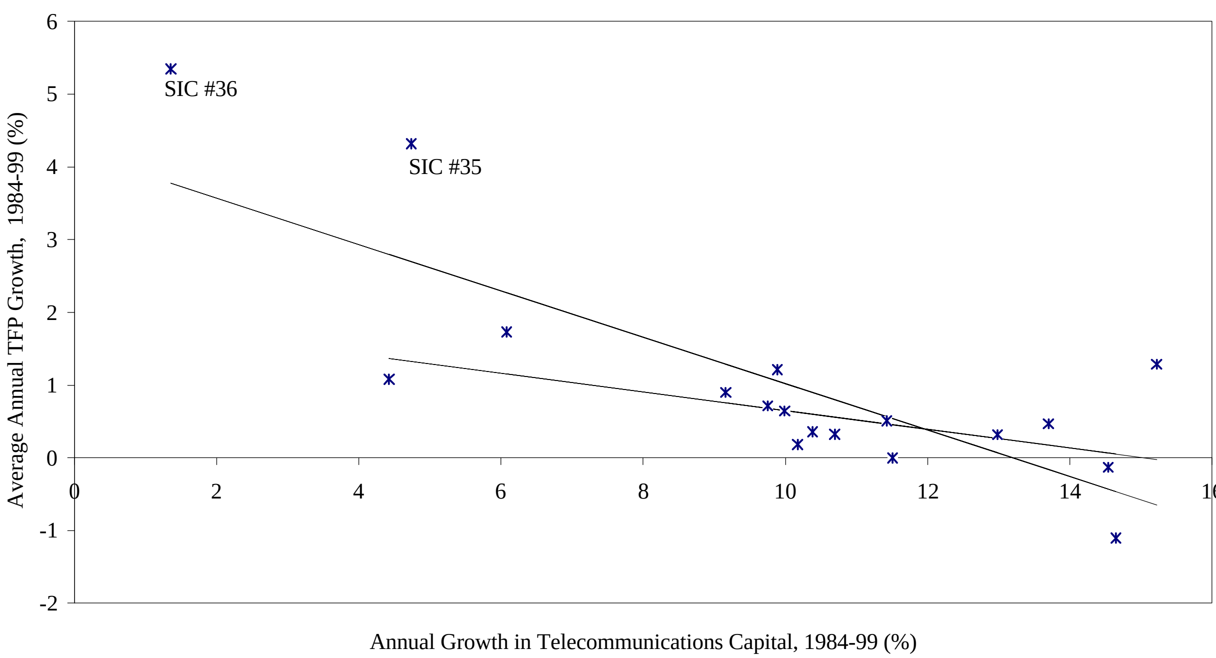
Chart 1: TFP Acceleration vs. ICT Intensity for U.S. Manufacturing Industries



Note: Steep line is fitted values from an OLS regression using all 18 industries. Flat line is fitted values from an OLS regression excluding SIC #35 and #36. See Footnote #20 in text for details.

Chart 2: TFP Growth vs. Telecommunications Capital Growth for U.S. Manufacturing Industries



Note: Steep line is fitted values from an OLS regression using all 18 industries. Flat line is fitted values from an OLS regression excluding SIC #35 and #36. See Footnote #23 in text for details.

Table 1: Industry Size and ICT Intensity for U.S. Manufacturing Industries

Industry	SIC	Gross Output ($B)		ICT Capital Share (%)		ICT
		1984	1999	1984	1999	Intensive
Private Business		na	na	7.7	16.1	
Nonfarm Business		na	na	8.2	16.5	
Manufacturing	20-39	1466.9	2,618.2	6.0	11.5	
Lumber and wood products	24	41.7	83.0	1.9	4.7	0
Furniture and fixtures	25	30.7	70.0	3.4	9.1	1
Stone, clay, and glass products	32	47.0	85.2	7.9	7.2	1
Primary metal industries	33	89.8	125.6	2.2	6.6	1
Fabricated metal products	34	128.9	225.2	2.8	7.3	0
Industrial machinery and equipment	35	183.5	348.2	16.1	32.4	1
Electronic and other electric equipment	36	141.4	295.3	15.3	16.6	1
Motor vehicles and equipment	37	228.3	497.5	5.0	9.6	1
Instruments and related products	38	89.6	155.6	14.7	29.3	1
Miscellaneous manufacturing industries	39	27.7	48.6	2.4	6.8	0
Food and kindred products	20	241.9	408.3	2.3	5.0	0
Tobacco products	21	na	na	2.7	4.8	0
Textile mill products	22	40.2	57.3	2.7	12.6	0
Apparel and other textile products	23	53.0	75.8	4.0	9.1	1
Paper and allied products	26	71.3	128.6	2.2	6.0	0
Printing and publishing	27	96.4	191.6	5.5	31.3	1
Chemicals and allied products	28	149.1	305.2	2.7	7.4	1
Petroleum and coal products	29	181.5	166.0	2.3	2.6	0
Rubber and miscellaneous plastics products	30	69.6	159.3	2.9	10.4	0
Leather and leather products	31	na	na	3.7	6.2	0
Mean of 20 Manufacturing Industries				5.1	11.3	
Median of 20 Manufacturing Industries				2.9	7.4	

Notes: Gross output is total value of shipments, measured in billions of current dollars and adjusted for inter-industry sales. ICT capital share is current dollar capital services for computer hardware, software, and telecommunications equipment as a percent of total capital services. ICT-intensive industries (ICT Intensive = 1) are defined as those with a 1993 ICT capital share above the median for the 20 manufacturing industries.

Source: Bureau of Labor Statistics.

Table 2: Industry Changes in Productivity Growth

Industry	ALP Growth 1984-93	ALP Growth 1993-99	ALP Growth Change	TFP Growth 1984-93	TFP Growth 1993-99	TFP Growth Change
Private Business	1.66	2.05	0.40	0.67	1.06	0.39
Nonfarm Business	1.51	1.98	0.47	0.50	0.97	0.46
Manufacturing	2.75	4.02	1.27	0.86	2.37	1.51
Lumber and wood products	0.15	0.15	0.00	0.24	-0.68	-0.93
Furniture and fixtures	1.54	3.13	1.59	0.33	0.68	0.36
Stone, clay, and glass products	1.54	2.42	0.88	1.27	1.13	-0.14
Primary metal industries	2.47	2.02	-0.45	1.32	0.73	-0.60
Fabricated metal products	1.34	2.06	0.72	0.20	0.59	0.40
Industrial machinery and equipment	5.23	9.62	4.39	3.13	6.10	2.96
Electronic and other electric equipment	6.38	13.57	7.20	3.52	8.08	4.56
Motor vehicles and equipment	2.57	4.58	2.01	-0.37	1.02	1.39
Instruments and related products	3.99	3.16	-0.83	1.00	0.75	-0.26
Miscellaneous manufacturing industries	0.97	1.90	0.93	-0.24	1.17	1.41
Food and kindred products	1.59	1.14	-0.44	-0.05	0.08	0.14
Tobacco products	na	na	na	na	na	na
Textile mill products	3.01	3.56	0.55	1.73	1.73	-0.01
Apparel and other textile products	2.58	6.76	4.18	-0.01	1.80	1.82
Paper and allied products	1.68	1.81	0.13	0.51	0.05	-0.46
Printing and publishing	-0.42	0.63	1.05	-1.36	-0.72	0.64
Chemicals and allied products	2.14	3.17	1.04	0.22	1.28	1.06
Petroleum and coal products	3.96	3.14	-0.82	0.52	0.49	-0.03
Rubber and miscellaneous plastics products	3.08	3.06	-0.02	1.32	1.23	-0.09
Leather and leather products	na	na	na	na	na	na
Mean of 18 Manufacturing Industries	2.43	3.66	1.23	0.74	1.42	0.68
Median of 18 Manufacturing Industries	2.30	3.10	0.80	0.42	0.88	0.25

Notes: All figures are annual average growth rates. Means and medians are of period averages.

Source: Bureau of Labor Statistics.

Table 3: Difference in Difference Estimates of ALP and TFP Growth

	ALP Growth		TFP Growth	
	All Industries	Exclude ICT-Producing	All Industries	Exclude ICT-Producing
	1984-93 vs. 1993-99			
Constant	1.970***	1.970***	0.528**	0.528**
	(0.433)	(0.435)	(0.232)	(0.232)
ICT Dummy	0.832	0.081	0.377	-0.228
	(0.745)	(0.614)	(0.523)	(0.390)
Time Dummy	0.133	0.133	0.054	0.054
	(0.201)	(0.202)	(0.232)	(0.233)
Time Dummy*ICT Dummy	1.972**	1.051*	1.124*	0.479
	(0.791)	(0.568)	(0.548)	(0.373)
Time Dummy +	2.105**	1.184**	1.178**	0.532*
Time Dummy*ICT Dummy	(0.764)	(0.530)	(0.496)	(0.292)
R^2	0.10	0.03	0.06	0.01
No. of Obs.	270	240	270	240
	1973-93 vs. 1993-99			
Constant	1.969***	1.969***	0.495	0.495
	(0.309)	(0.310)	(0.297)	(0.299)
ICT Dummy	0.450	-0.126	0.077	-0.348
	(0.588)	(0.509)	(0.454)	(0.389)
Time Dummy	0.134	0.134	0.087	0.087
	(0.363)	(0.365)	(0.327)	(0.328)
Time Dummy*ICT Dummy	2.354**	1.258*	1.425**	0.598
	(0.933)	(0.645)	(0.670)	(0.409)
Time Dummy +	2.488**	1.392**	1.511**	0.685**
Time Dummy*ICT Dummy	(0.860)	(0.532)	(0.585)	(0.244)
R^2	0.06	0.02	0.04	0.00
No. of Obs.	468	416	468	416

Notes: All estimates are ordinary least squares. Robust standard errors in parentheses are corrected to allow for correlation in residuals over time for each industry. ICT Dummy = 1 if 1993 ICT capital share is above the median; ICT Dummy = 0 otherwise. Industries breakdown is shown in Table 1. Time Dummy = 1 if year>1993; Time Dummy = 0 otherwise. ICT-producing industries are SIC #35 and #36.

Table 4: Production Function and TFP Regressions, 1984-99

	OLS		IV	
	Output as Dependent Variable			
ICT Capital	-0.070**		-0.086*	
	(0.033)		(0.041)	
Computer Capital		-0.022		-0.071**
		(0.018)		(0.029)
Telecomm Capital		-0.204***		-0.242***
		(0.041)		(0.065)
Other Capital	0.518***	0.531***	0.582**	0.918***
	(0.179)	(0.112)	(0.207)	(0.184)
Hours	0.196**	0.297***	-0.055	0.339
	(0.074)	(0.065)	(0.168)	(0.237)
Intermediate Inputs	0.481***	0.431***	0.758***	0.191
	(0.073)	(0.062)	(0.240)	(0.377)
Sum of Coefficients	1.125	1.032	1.198	1.135
	(0.167)	(0.107)	(0.232)	(0.142)
	TFP as Dependent Variable			
ICT Capital	-0.070*		-0.086*	
	(0.038)		(0.043)	
Computer Capital		-0.018		-0.067*
		(0.020)		(0.036)
Telecomm Capital		-0.216***		-0.271***
		(0.042)		(0.077)
Other Capital	0.405**	0.415***	0.470**	0.836***
	(0.182)	(0.108)	(0.210)	(0.216)
Hours	-0.130	-0.024	-0.344	0.098
	(0.087)	(0.075)	(0.207)	(0.322)
Intermediate Inputs	-0.051	-0.104	0.187	-0.441
	(0.088)	(0.075)	(0.278)	(0.466)

Notes: All regressions include 270 observations (15 years for 18 industries), use first differences of log-levels, and include year dummy variables. Robust standard errors in parentheses are corrected to allow for correlation in residuals over time for each industry. OLS is ordinary least squares. IV is instrumental variable estimates using 1-period and 2-period lags of the independent variables and year dummy variables as the instruments.

Table 5: Robustness Checks for Production Function and TFP Regressions, 1984-99

	Drop Year Dummies	Robust Regression	Include ICT-Producing Dummy OLS	Include ICT-Producing Dummy IV	Fixed Effects
			Output as Dependent Variable		
Computer Capital	0.022	-0.038*	-0.002	-0.029	-0.003
	(0.016)	(0.020)	(0.024)	(0.031)	(0.012)
Telecomm Capital	-0.152***	-0.139***	-0.059	-0.088	-0.036
	(0.038)	(0.024)	(0.038)	(0.067)	(0.040)
Other Capital	0.457***	0.437***	0.269***	0.431*	0.149***
	(0.134)	(0.069)	(0.066)	(0.220)	(0.053)
Hours	0.282***	0.291***	0.273***	0.251	0.303***
	(0.061)	(0.056)	(0.054)	(0.155)	(0.074)
Intermediate Inputs	0.480***	0.437***	0.420***	0.336	0.354***
	(0.045)	(0.035)	(0.057)	(0.302)	(0.056)
ICT-Producing Dummy			3.610***	3.227***	
			(0.368)	(0.375)	
Sum of Coefficients	1.090	0.989	0.902	0.901	0.767
	(0.107)	(0.072)	(0.081)	(0.132)	(0.081)
			TFP as Dependent Variable		
Computer Capital	0.017	-0.026	0.003	-0.022	-0.007
	(0.015)	(0.020)	(0.025)	(0.027)	(0.019)
Telecomm Capital	-0.151***	-0.171***	-0.064	-0.099*	-0.033
	(0.040)	(0.028)	(0.040)	(0.059)	(0.036)
Other Capital	0.342**	0.312***	0.141*	0.295	0.058
	(0.131)	(0.070)	(0.075)	(0.207)	(0.093)
Hours	-0.050	-0.014	-0.048	0.000	-0.011
	(0.059)	(0.058)	(0.063)	(0.175)	(0.056)
Intermediate Inputs	-0.051	-0.114***	-0.116	-0.276	-0.201***
	(0.051)	(0.035)	(0.068)	(0.212)	(0.040)
ICT-Producing Dummy			3.789***	3.578***	
			(0.459)	(0.705)	

Notes: All regressions include 270 observations (15 years for 18 industries) and use first differences of log-levels. All regressions except the first column include year dummy variables. Standard errors are in parentheses. All standard errors except the second column are robust to heteroskedasticity and corrected to allow for correlation in residuals over time for each industry. The first column is OLS. Robust regression applies decreasing weights to observations with large residuals; see text for details. IV is instrumental variable estimates, using 1-period and 2-period lags of the independent variables and year dummy variables as the instruments. ICT-Producing Dummy = 1 for SIC #35 and #36, ICT-Producing Dummy = 0 otherwise. Fixed effects includes an industry-specific dummy variable in the first difference regression.