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Information technology and the U.S. productivity acceleration

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Whatever happened to the New Economy? The good news is U.S. productivity continues to grow at a healthy pace. This article sheds light on why information and communications technology may continue to pay dividends for years to come.

In the long run, a rising standard of living depends primarily on rising productivity. For this reason, economists have regarded the increase in U.S. productivity growth since the mid-1990s as an excellent development. But still unresolved is the role of information technology (computers, software, communications, and the like) in the productivity acceleration. In particular, is it the sectors that *produce* information and communications technology (ICT) or those that *use* it that are having the greatest impact on productivity growth?

1. ICT contribution to the TFP acceleration

	Period	TFP accelerated	Contribution of ICT	Contribution of non-ICT
		(- - - - *percentage points* - - - -)		
Council of Economic Advisers[a]	('95–'02) – ('73–'95)	1.21	0.13	1.08
Basu, Fernald, Oulton, and Srinivasan[b] (2003)	('95–'00) – ('90–'95)	1.17	0.29	0.88
Jorgenson, Stiroh, and Ho (2002)	('95–'00) – ('90–'95)	0.40	0.12	0.27
Oliner and Sichel (2002)	('96–'01) – ('91–'95)	0.41	0.36	0.06

[a]Structural TFP figures, where output is based on average of income- and product-side measures.

[b]Figures do not include an adjustment for changes in labor quality.

Notes: ICT and non-ICT contributions may not add up to TFP acceleration due to rounding. See endnotes for citations.

Much of the research on the post-1995 productivity acceleration suggests that while the ICT sectors of the economy played an important role in the acceleration in total factor productivity (TFP)—a broad measure of productivity (explained further below)—most of the TFP acceleration took place *outside* of the production of ICT goods and software.

In this *Chicago Fed Letter*, we report on recent work that suggests that ICT can itself explain some of the measured acceleration in TFP in sectors *using* it. Importantly, benefiting from ICT requires substantial complementary investments in learning, reorganization, and the like, so that the payoff in terms of measured output may be long delayed. The development of electric power as a general purpose technology provides a useful analogy. As a result, it appears likely that relatively strong productivity growth can remain for an extended period.

Explaining productivity

Economists identify three direct factors that boost labor productivity, defined as output per hour. First, labor productivity generally rises over time because workers have more and better capital to work with—e.g., auto workers today work with much larger and more sophisticated assembly lines than those in Henry Ford's Model T assembly plants; workers have more "computer" capital to work with, because their computers are better and faster as well as more plentiful. Second, productivity rises over time because of work force gains in education and skills,[1] allowing workers to produce more in each hour worked. Finally, labor productivity rises because of what economists call total factor productivity. TFP is a catchall term for everything not otherwise explained, but the main reason TFP rises over time is innovation—new products and new processes.

With this framework in mind, we can identify two channels for ICT to affect aggregate labor and TFP growth.[2] First, innovation in the sectors *producing* ICT goods contributes directly to economy-wide TFP growth. Second, the *use* of ICT capital goods contributes directly to labor productivity through capital deepening: By reducing the effective cost to a user of deploying capital, falling ICT prices induce firms to increase their desired capital stock.

The 2003 *Economic Report of the President* (Council of Economic Advisers) provides a fairly recent estimate of the contribution of ICT to the acceleration in labor productivity. The report states that after controlling for business cycle effects, labor productivity accelerated 1.73% per year in the 1995–2002 period from the 1973–95 period. Of this acceleration, ICT contributed 0.53 percentage points per year: ICT capital deepening, i.e., that each worker had more ICT capital to work with, contributed 0.40 percentage points per year; and computer sector TFP contributed 0.13 percentage points (column 3 of figure 1). Non-ICT capital-deepening contributed 0.11 percentage points per year; labor quality made a slight, negative contribution (i.e., it improved at about the same rate in the 1973–95 period as in the 1995–2002 period).

By contrast, structural TFP *excluding* ICT-sector TFP contributed 1.08 percentage points more per year from 1995 to 2002 than from 1973 to 1995. Figure 1 shows a range of other recent studies that provide a similar TFP decomposition.

All of these studies show some substantial contribution to the overall TFP acceleration coming from sectors that *use* rather than produce ICT. (The smallest figure for the non-ICT TFP acceleration is from Oliner and Sichel, 2002, who discount their small non-ICT contribution on technical grounds.) The causes of the TFP acceleration in ICT production are reasonably well understood. New product development, resulting especially from R&D, has led to rapid improvements in computer technology. For example, as Jorgenson (2001) and McKinsey (2001) discuss,[3] competition between two major chip manufacturers, Intel and AMD, led to more rapid introduction of new semiconductor chips in the post-1995 period, and this faster pace of technological rollout appears to explain a large share of the ICT technology acceleration.

By contrast, there is little information about the source of the TFP acceleration outside of ICT production. In particular, there is no presumption that the *use* of ICT should have any particular effect on measured TFP. However, recent work (much of it microeconomic, firm-level, and anecdotal) suggests that there are important—but often indirect and hard to foresee—potential ways for ICT to affect measured production and productivity in sectors using ICT.

For example, Hubbard (2002) discusses how on-board computers have substantially raised TFP in trucking, in large part by raising capacity utilization.[4] Dispatchers have real-time access to information on truck location and truck loads; customers, truckers, and intermediaries reduce costly transactions and search time; and firms have an easier time monitoring drivers (thereby making contracts easier to specify and enforce).

ICT as a general purpose technology

In theoretical terms, much of this discussion revolves around the notion of "general purpose technologies" (GPTs). This term is usually applied to innovations, such as electricity or information technology, that have a pervasive and wide-ranging effect on how firms do business or even how people live.[5]

What kinds of links might there be between ICT use and measured TFP? Conceptually, one can separate these potential links into two categories: Purposeful co-invention, the accumulation of intangible "complementary capital"; and externalities of one sort or another. First, firm-level studies suggest that benefiting from ICT investments requires substantial and costly co-investments in complementary capital.[6] For example, firms that use computers more intensively may reorganize production, thereby creating "intangible capital" in the form of organizational knowledge. These investments may include resources diverted to learning; they may involve purposeful innovation arising from R&D.

The resulting "organizational capital" is analogous to physical capital in that companies accumulate it in a purposeful way. We can think of this complementary capital as an additional input into production; it differs from ordinary capital and labor in that it is not directly observed.[7] In other words, this channel is, in essence, the standard capital-deepening story, except that the input of intangible capital may not be measured.[8]

Second, the GPT literature suggests the likelihood of sizeable externalities to ICT. For example, successful new managerial ideas—including those that take advantage of ICT, such as the use of a new business information system—seem likely to diffuse to other firms, which learn by watching and analyzing the experimentation, the successes, and, importantly, the mistakes made by others. Indeed, firms that *don't* use computers more intensively may also benefit from spillovers of intangible capital. For example, if there are sizable spillovers to R&D, and if R&D is more productive with better computers, then even firms that don't use computers intensively may benefit from the knowledge created by computers.

The nature of the co-inventions and externalities suggests that we should not expect the benefits of ICT to diffuse instantaneously. First, if large complementary investments and innovations are necessary, diffusion of ideas from one firm to another will inevitably take time. Second, Bresnahan and Trajtenberg (1995) note that co-invention often requires "coordination between agents located far from each other along the time and technology dimension" (p. 3), so that institutional arrangements and market structure are likely to matter; these factors are likely to differ across countries. Third, adoption costs and adoption benefits may differ across firms, so that low adoption cost/high adoption benefit firms may adopt new technologies first.[9] Finally, spillover effects may be stronger at closer distances (e.g., within Silicon Valley).

Electricity as a general purpose technology

A number of people have argued that the diffusion of electricity provides an appropriate analogy for the likely delayed benefits of ICT.[10] Certainly, electricity provides numerous specific examples of how a GPT transforms business and household life. Benefiting from electricity, however, required dramatic reorganizations of production as well as a spate of new products. As a result, the benefits took many decades to unfold.

In particular, substantial co-invention was necessary to reap the major benefits of electrification. The major innovations in electricity per se were the invention of the electric dynamo, which changes mechanical power into electric power, and the subsequent invention of the electric motor. At first, factories simply replaced existing large steam-driven engines with large electrical motors as the power source driving the central shafts and turbines. Not surprisingly, the benefits were small and incremental. But engineers began to realize that electric motors were much more flexible than steam power, allowing them to redesign factories in much more efficient ways, with small electrified machines throughout the factory; workflow rather than proximity to the central power shaft became the organizational principle.[11] Coupled with innovative ideas such as Henry Ford's assembly line, electric power run through wiring proved to be an advancement from the original power shafts, which would have been ill-suited for the assembly line.[12] Ford's new system then led to additional benefits through the introduction of interchangeable parts and mass production, which both revolutionized production.

Once houses were electrified, new products were invented that directly benefited households. Gordon (2000) observes the myriad ways in which, after a substantial lag, new electrified consumer appliances greatly improved the quality of life—e.g., by eliminating manual laundry with electric washing machines and food spoilage with refrigerators.[13] Greenwood, Shesadri, and Yorukoglu (2002) argue that household appliances helped women move into the labor force by making household chores easier and faster and creating more free time (see also Jovanovic and Rousseau, 2003).[14]

Evidence for ICT as a GPT

As noted earlier, the empirical literature suggests that measured TFP reflects an acceleration in sectors that *use* (rather than simply produce) ICT products. TFP can, of course, move around for a lot of reasons unrelated to ICT. For example, it could be that the U.S. experienced broad-based managerial innovations that raised TFP growth throughout the economy. Nevertheless, the GPT considerations suggest that the acceleration in measured TFP—and the managerial innovations that cause it—could be associated with the use of ICT.

For example, Brynjolfsson and Hitt (2003)[15] find that in a sample of 527 large U.S. firms from 1987 to 1994, the full benefits of computers for output and productivity do not appear to be realized for at least five to seven years. They interpret their results as suggesting the importance of combining computer investments with "large and time-consuming investments in complementary inputs, such as organizational capital."

At a more aggregated industry level, several studies explore whether TFP growth across industries is correlated with ICT intensity. In contrast to firm-level studies, these industry studies rarely find much contemporaneous correlation between ICT capital and TFP growth (e.g., Stiroh, 2002, and Wolff, 2002).[16] But given the GPT nature of ICT, the contemporaneous correlation need not be positive—even if ICT is, in fact, an important contributor to measured TFP. For example, implementing new ICT intensive production methods likely requires a diversion of resources toward learning and organizational change, which temporarily disrupts production.

Wolff does find that U.S. industries investing heavily in ICT have greater changes in their occupational mix and the composition of intermediate inputs, consistent with substantial reorganization. Gust and Marquez (2003) find that industrial countries with a more burdensome regulatory environment (especially affecting labor market practices) adopted ICT more slowly and also had slower TFP growth.[17] Those findings are consistent with the notion that the uptake of ICT could affect measured TFP in the sectors using the ICT.

Basu, Fernald, Oulton, and Srinivasan (2003) find that the industry data are reasonably consistent with the predictions that in sectors using ICT, ICT capital growth should, with long lags, be positively associated with TFP growth. In particular, they find evidence that ICT capital investments in the 1980s and early 1990s are positively correlated with the TFP acceleration in the late 1990s.

Conclusion

At the peak of the "New Economy" hype of the late 1990s, many argued that "The Internet changes everything." The presumption was that the changes would take place almost overnight. But the lessons from previous general purpose technologies such as electricity, as well as recent theoretical and empirical work, suggest that the necessary complementary investments and innovations take place only with long lags. Thus, it could be that the promise of the Internet and other new technologies will continue to be realized—but over a long period.

More generally, though, the sustained, strong productivity performance of the U.S. economy gives grounds for cautious optimism that when the overhang of recent bad shocks ends, the economy could return to relatively robust rates of growth. To the extent that ICT is, indeed, a general purpose technology, the returns to innovation (whether managerial innovations or the development of new products and processes) are likely to remain high for some time to come.

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[1] See D. Aaronson and D. Sullivan, 2001, "Growth in worker quality," *Economic Perspectives*, Federal Reserve Bank of Chicago, Vol. 25, No. 4, pp. 53–74.

[2] See D. W. Jorgenson, 2001, "Information technology and the U.S. economy," *American Economic Review*, Vol. 91, March, pp. 1–32; D. W. Jorgenson, M. S. Ho, and K. J. Stiroh, 2002, "Growth of U.S. industries and investments in information technology and higher education," manuscript, October 7; or S. D. Oliner and D. E. Sichel, 2002, "Information technology and productivity: Where are we now and where are we going?," *Economic Review*, Federal Reserve Bank of Atlanta, Vol. 87, No. 3, pp. 15–44.

[3] McKinsey Global Institute, 2001, "U.S. productivity growth 1995–2000: Understanding the contribution of information technology relative to other factors," Washington, DC, October.

[4] T. N. Hubbard, 2002, "Information, decisions, and productivity—On-board computers and capacity utilization in trucking," National Bureau of Economic Research, working paper, No. 8525.

[5] See T. F. Bresnahan and M. Trajtenberg, 1995, "General purpose technologies: 'Engines of growth?'," *Journal of Econometrics*, Special Issue, No. 65, January, pp. 83–108; and B. Jovanovic and P. L. Rousseau, 2003, "General purpose technologies," manuscript. The remainder of this section draws heavily on S. Basu, J. Fernald, N. Oulton, and S. Srinivasan, 2003, "The case of the missing productivity growth: Or, does information technology explain why productivity accelerated in the United States but not the United Kingdom?," Federal Reserve Bank of Chicago, working paper, No. 03-08.

[6] See E. Brynjolfsson and L. M. Hitt, 2000, "Beyond computation: Information technology, organizational transformation, and business performance," *Journal of Economic Perspectives*, Vol. 14, No. 4, pp. 23–48, and T. F. Bresnahan, undated, "The mechanisms of information technology's contribution to economic growth," presentation at the Saint-Gobain Centre for Economic Research.

[7] See J. Greenwood and M. Yorokoglu, 1997, *Carnegie-Rochester Conference Series on Public Policy*, Vol. 46, pp. 49–95; A. Hornstein and P. Krusell, 1996, "Can technology improvements cause productivity slowdowns?," *NBER Macroeconomics Annual*, Bernanke and Rotemberg (eds.), Cambridge, MA: National Bureau of Economic Research; and J. Laitner and D. Stolyarov, 2001, "Technological change and the stock market," University of Michigan, manuscript.

[8] These GPT considerations suggest that the production function is mismeasured, because we don't observe all inputs (the service flow from complementary, intangible capital) or all outputs (the investment in complementary capital). Hence, true TFP is mismeasured. In addition, many of the benefits of ICT may show up in better quality products that are better matched to consumer needs, which are inherently difficult to measure.

[9] See A. D. Chandler, Jr., 1977, *The Visible Hand*, Cambridge: Harvard University Press and Helpman and Trajtenberg, 1998, "Diffusion of general purpose technologies," in *General Purpose Technologies and Economic Growth*, E. Helpman (ed.), Cambridge: MIT Press.

[10] On the other hand, R. Gordon, 2003, "High tech innovation and productivity growth: Does supply create its own demand?," National Bureau of Economic Research, working paper, No. 9437, argues that electricity is a far more important innovation than ICT will ever be.

[11] P. A. David, 1990, "The dynamo and the computer: A historical perspective on the modern productivity paradox," *American Economic Review Papers and Proceedings*, Vol. 50, No. 2, pp. 355–361.

[12] David and G. Wright, 1999, "General purpose technologies and surges in productivity: Historical reflections on the future of the ICT revolution," manuscript.

[13] R. Gordon, 2000, "Does the 'new economy' measure up to the great inventions of the past?," *Journal of Economic Perspectives*, Vol. 94, pp. 627–642.

[14] J. Greenwood, A. Seshadri, and M. Yorukoglu, 2002, "Engines of liberation," *Economie d'Avant Guarde*, No. 2.

[15] E. Brynjolfsson and L. M. Hitt, 2003, "Computing productivity: Firm-level evidence," MIT-Sloan, working paper, No. 4210-01, also eBusiness@MIT, working paper, No. 139, June.

[16] K. J. Stiroh, 2002, "Information technology and the U.S. productivity revival: What do the industry data say?," *American Economic Review*, Vol. 92, No. 5, pp. 1559–1576, and E. N. Wolff, 2002, "Productivity, computerization, and skill change," National Bureau of Economic Research, working paper, No. 8743.

[17] C. Gust and J. Marquez, 2003, "International comparisons of productivity growth: The role of information technology and regulatory practices," *Labour Economics*, Special Issue on Productivity, Gilles Saint-Paul (ed.), forthcoming.