# The 'Vanishing' IT Productivity: A Simple Theory

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## Abstract

*The perceived phenomenon that huge investments in information technology (IT) over the past four decades have yielded a very small gain in productivity has been dubbed the "IT paradox." Researchers have tried various methods to prove or disprove the "paradox." This article highlights the challenges researchers have faced and proposes a simple theory to explain what seems to be a vanishing contribution of IT to productivity growth.*

## 1. Introduction

Over the past decade, scores of articles and books have been devoted to the issue of IT productivity. More specifically, some of these articles and books addressed the IT productivity paradox, the notion that despite huge investments in IT, the technology has not yielded significant productivity gains. Strong statements were made about IT productivity, from Solow's [38] "You can see the computer age everywhere but in the productivity statistics" which he recounted thirteen years later [43] to [37] "there's not a shred of evidence to show that people are putting out more because of investments in technology" a decade later.

The IT productivity paradox was raised by studies that used production theory. The researchers tested the correlation between IT expenditure and productivity. The studies found either no positive correlation [4, 25] or that the costs exceeded the benefits [28]. The great majority of studies found that investment in IT did not bring about productivity growth or yielded only a very low increase in productivity. The studies and the resultant conclusions address individual firms, whole industries, and national economies. In the majority of studies, "investment in IT" is defined as national investment in hardware, value of IT "stock" for the sampled years, other national statistics of dollar investments in IT, corporate budgets for hardware and software, or whatever the sampled firms defined in their own accounting as IT expenditures. While many economists used a variety of methods to measure growth in productivity [28, 5, 7, 10, 11, 19, 23, 23, 25, 30, 32, 33, 35, 36], many studies speak of productivity in a more general manner. Under the umbrella of "productivity," the researchers have measured profitability, revenue, market value of the firm, return on investment on individual projects, and performance, where performance is defined differently as any of these measurements or a combination thereof. For example, Navarrete and Pick [29] argue that the IT productivity paradox did not exist in the Mexican banking industry during the period 1982-1992. They base the argument on their finding that increased investment in IT was positively associated with the industry's net profits and return on assets.

Economists distinguish between labor productivity and multifactor productivity. Labor productivity is the ratio of the output of goods and services to the labor hours devoted to the production of that output. Multifactor productivity relates output to a combination of inputs used in the production of that output, such as labor and capital or labor, capital, energy and materials. It seems that the greater interest of businesses is in labor productivity, especially in developed countries, where labor is relatively an expensive resource. Thus, we will address mainly studies that attempted to measure the contribution of IT to labor productivity (hereinafter referred to as "IT productivity"): an increase in the ratio of units produced of products or services to the amount of labor spent on the production of these units, as the result of procurement of IT. This article reviews the major approaches used and the findings in the IT productivity literature, cites the difficulties in measuring IT productivity, and offers a theory to explain the seeming lack of IT productivity.

## 2. What Has Been Measured

Readers of IT productivity literature should wonder: while the studies speak of productivity, many measure all but productivity. Many studies that purport to measure productivity actually measured other things. Some researchers tried to evaluate the "value" of IT [4]. However, value is different things to different people, and, as Lucas [26] wonders, "what is value?" Even if value were well defined, it is doubtful we could measure

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it directly in any solid economic terms. Value could be better decision-making, employee satisfaction, better customer service, and many other benefits, some of which may indirectly contribute to productivity, some of which may not, and some of which cannot be measured as productivity.

Some studies [39, 40, 41], speak of productivity but measure the relationship between investment in IT and corporate earnings. However, increase in revenue and/or profit may or may not have to do with investment in IT. In any case, change in revenue or profit is not change in productivity, and the former are poor surrogates for the latter.

A handful of studies attempted to measure the linkage between IT expenditure and real output [10, 11, 6, 22], but they were not conclusive despite the great effort of the researchers in using detailed data and rigorous quantitative analytical techniques, such as production functions.

Brynjolfsson and Yang [13] surveyed over 150 studies, from which they concluded that in the 1980s and early 1990s not only was the link between IT and productivity not conclusive, but also that measuring such a link was practically impossible due to lacking data and use of inadequate analytical methods. They conclude their article with optimism about both better data and more rigorous methods, but there does not seem to be more detailed data now than there was at the time they wrote the article.

## 3. What Is Information Technology?

The answer to the question "What is information technology" is simple: it is hardware, software, telecommunications, and the services of IT personnel, whether employed in-house or purchased. However, few studies have accounted for *all* these elements. In fact, a large number of studies have relied on a single element: hardware. The reason is simple: this is the only element on which there are reliable government statistics in the U.S. and a few other countries. The Strategic Planning Institute has accumulated data on IS services, which has been used in studies conducted by Strassman [40]. It is difficult to assess how reliable those figures are. In their 1999 study, Bynjolfsson and Yang did include investment in software and worker training, but that study assesses firm value expressed as stock market valuation rather than productivity.

Estimates of annual contribution of investment in computers to total product output have exceeded $.60 output per dollar invested [10, 11, 24, 17]. In one of the most ambitious studies on IT productivity, Brynjolfsson and Hitt [11] used Cobb-Douglas production functions to search for return on IT investment. They found out that for the sampled firms (all with five-year average sales of over $7 billion) the rewards were great: a marginal gain in product of $0.81 for every dollar spent on IT capital and $2.62 on every dollar spent on the labor of IT personnel. While the approach – using production functions and marginal product rather than regression functions and profits – may be the proper one for such research, the study suffers from one shortcoming found invariably in all such studies: partial data.

The researchers used only IT capital and IT personnel as "IT investment." Perhaps this is the reason for the huge return on IT investments they found. Indeed, their conclusion drew some criticism [26]. The greater and growing part of IT over the past two decades has been software and IT services, not hardware. IT services include such projects as installation of ERP systems by consultants, which usually amount to millions of dollars per system. In addition, companies spend huge sums on the implementation of telecommunications, an expenditure category that was not considered in the study. An analysis of data from 800 large firms suggests that the ratio of non-hardware expenditure to hardware expenditure is 9 to 1 [19]. Namely, up to 90% of the investment in IT has not been accounted for in most of the studies of IT productivity so far. One exception is a study conducted by Oliner and Sichel (2000) in which they calculate the contribution of software and telecommunication to labor productivity but caution about the limitations of their calculations.

The exclusion of some IT spending data from the studies so far is not due to lack of attention on the part of researchers. Obtaining the figures is practically impossible. So far, spending on software, IT services, and telecommunications has not been collected and tabulated by government agencies or trade organizations in a manner that enables productivity research without controversial manipulation of the data.

This is also one of the reasons why many researchers have focused their attention on individual firms rather than on national economies. Some companies account for IT investments separately from other capital investments. And if researchers cannot find data on actual expenditure, they often rely on budgetary data as a proxy.

However, the definition of what is IT expenditure may vary across firms.

## 4. Where Has Profitability Vanished?

In terms of profitability, businesses have experienced with IT what they have experienced with any other new technology. The economics of a new technology follows a simple cycle: economic profit thanks to use of technology only by the particular firm or a small number of businesses in the industry, the spread of the technology throughout the industry, the reaping of productivity gains (which is diminishing), a continuous decrease in prices of their products (which is enabled by the productivity gains), and, eventually, a larger quantity of the products sold for a lower price at a low profit margin. When we get to the end of the cycle, expect no productivity gains. At this point, businesses *must* use the new technology to survive.

Technologists speak of “mature technologies.” A mature technology is one with which workers have become comfortable and which they perceive as an integral part of their work environment. In a similar way, we can speak of the economic maturity of technology. Technology matures when it is no longer a novelty but a necessity. While we may expect productivity gains from new technology, we should not expect significant or any productivity gains from a mature technology; it now has no “innovation benefits” and must be used by the business to survive.

Consider: Does any company realize productivity gains when it uses telephones or fax machines? Not now. But the early adopters of these technologies might have seen some productivity gains in the first few years of such usage compared with the years before the adoption. If you think that equipping your employees with computers does not gain you any productivity, you are absolutely right. But if you do not use PCs, your business will simply not survive.

A mere two centuries ago, the great majority of the workforce consisted of farmers and people who worked with these farmers. Now, in the United States only two percent of working Americans make a living from work on farms. These people not only feed Americans better than a century ago; they also feed with their products millions of people in other countries. The reason for this huge productivity is better agricultural equipment and better methods. Should any farmer expect productivity gains from employing a tractor, combine, and computer-controlled sprinklers? Of course not.

## 5. Research Challenges

Robert M. Solow’s statement of [38], “You can see the computer age everywhere but in the productivity statistics” raises the question, “What statistics?” Do the statistics that we have considered so far really measure productivity and are they meaningful in such inquiry? Similarly, attempts to measure productivity at the firm level may be frustrating because of inadequate data on investment of all aspects of IT. (This is not to say that researchers’ attempts were not worthy or did not teach us anything about some aspects of IT productivity. On the contrary: They are worthy of our appreciation for their continued pursuit despite the difficulties.)

Productivity is the efficiency of input. Input may be one of various resources, but the most important resource about which productivity has been measured is labor. Thus, henceforth we will use the term “productivity” to mean “labor productivity.” To measure the contribution of a certain technology to productivity we must examine the relationship between units of investment in the technology and the increase of output units over the period of time in question. However, as we posit later, using the dollar value of outputs as a proxy for output units severely distorts the picture. In addition, the period over which the study occurs may impact the result significantly: if we measure over the first 3-4 years of using the technology, we may find significant productivity gains even if we measure output dollars because only a few pioneering organizations have used the technology over this period, and they may have enjoyed increased revenue as a result of producing an increased number of output units at prices that have not changed much. But if we measure over a period of 10-15 years, the prices of the sold output have probably decreased, so revenue (and therefore, output dollars) may have not changed or even decreased.

If we must measure output dollars, the results would reflect a more accurate picture if we performed not a longitudinal study but a cross section study of a large sample of technology users over a short period of time. This minimizes the distortion of revenue measurement because price changes would be smaller. When such longitudinal research is done, price inflation must be accounted for. Indeed, some researchers have done so [5, 23, 27]. In virtually all the studies that accounted for price changes, the researchers used GDP price deflators. Some accounted for prices changes by using Producer Prices Index (PPI) or Consumer Price Index (CPI). However, such price deflators include a large number of goods and services in their “baskets,” only a fraction of which are the goods and services of the sampled businesses, and only a small portion of which are IT goods and services. Thus, the researchers might have underinflated or overinflated prices.

The U.S. Bureau of Economic Analysis publishes quality-adjusted deflators for computer prices, but no such deflators are published for other components of IT, such as software, training, and IT services.

Studying across a large sample for a shorter period of time rather than conducting a longitudinal study of a smaller sample for a longer period of time would yield more accurate results than using deflators; industry and consumer price index deflators do not really deflate accurately either the specific output of a firm or the prices of the input with which we are dealing: IT. IT investments are “baskets” of capital expenditure, which include items whose prices have not changed at the same rate over the years.

One of the most ardent critics of IT productivity is Lester Thurow, former dean of the Sloan School at the Massachusetts Institute of Technology. One of the most prolific researchers in the field, whose studies argue that IT has made great productivity gains, is Eric Brynjolfsson, a senior professor at the very same institution. Interestingly, in newspaper stories covering Thurow's assertions refuting IT productivity, the former dean is seen sitting in his office with a personal computer standing on his desk. Has that computer contributed anything to the professor's productivity?

## 6. Challenges in Measuring It Productivity

There is a certain irony in trying to measure IT productivity. IT has been adopted faster, and probably contributed more productivity in service sectors than in manufacturing sectors. Yet, it is almost impossible to measure productivity gains in service sectors. It is easier to do that in industries that produce real goods. Here are the major challenges.

## 7. Challenges in Measuring Output

In their study of the relationship between IT expenditures and productivity in services, Quinn and Baily [33] conclude that the seemingly minuscule gains in measured productivity were biased because the data were so flawed that any simple conclusions were misleading. Let us recall that we have output in the numerator of the productivity ratio. How can we measure gains in service units? Service hours are a bad measure because an hour is always an hour; what is important is how much service you provide in that hour. Although some companies consider how many customers are served per hour or how many patients a doctor sees per hour, these ratios can vary because of policy rather than because of a better or worse technology used.

The task is easier when the product of is physical, such as so many barrels of oil or so many cubic feet of lumber. In some industries we can still quantify output relatively easily although the output is actually a service. For example, in the shipping industry output is measured in miles and ton-miles of truck-load (LT) and less-than-truckload (LTL). Note that in all these examples the output consists of a single product. Measuring productivity in production of a single product is easier than when measuring with several products: you can compare the number of apples you produced without a certain technology with the number of apples you produced with the technology, but if you want to compare the sizes of today's and yesterday's "baskets" of fruits, you must use a monetary value for the baskets instead of simply counting the fruit. Many businesses do not produce a single item but an array of items, which confounds the task of measuring overall productivity; to avoid use of monetary values, productivity must then be measured separately for each item, and the overall productivity of the business (or industry, for this matter) must be some kind of a weighted average.

Admittedly, even when products seem to be homogenous across firms in the same industry, there may still be some variations in the products due to different levels of quality. For example, a tone-mile of delivery may be on time or late, and the delivered goods may arrive damaged in 5% of deliveries or only 1% of deliveries. Yet, these differences pose a smaller challenge in measurement than does a combination of different products.

However we measure output, we confound the measure by using the monetary value of it. The number of dollars you can receive for your output has little to do with your ability to produce more or fewer units of the product. The same barrel of oil may fetch $24 dollars now but sold for $32 several months ago. This certainly does not mean you have become a less productive producer. As mentioned before, using price deflators may reduce the distortion but probably not eliminate it altogether. Thus, to measure the impact of IT on productivity, we must use physical output units.

In their efforts, researchers have used deflators to bring output units expressed in dollars to a common base year. Still, the manipulation may not yield true real output figures. The study that came very close to using real output in calculating IT productivity was conducted by Allen [1]. Measuring real units of electrical power output per employee in the U.S. electric utility industry, he found that about five years after significant IT investment, the output of this industry rose while the number of personnel decreased. As the prices of output in this industry did not change much over the years covered by the study, the distortion of real output is minimal.

## 8. Challenges in Measuring Input

Let us take the example of the lumber industry. The output, the numerator of our ratio, is cubic feet of lumber.

The input is IT resources. But how do you measure IT input? Apparently, there is no way of using physical units. In most of the studies, the researchers used "computing machinery" as the input variable. For example, Brynjolfsson et al. [8] used the Bureau of Economic Analysis category "Office, Computing and Accounting Machinery," which consists mainly of computers (but also other equipment, such as calculators). This is a shortcoming in IT productivity studies. Hardware is not the only component of IT; its financial value in the IT "basket" has consistently decreased over the years. Purchased software, software development, and software maintenance have been a larger component of IT for many years. At the least, the IT input figures used in any productivity study must include the following: Computing hardware, Telecommunications hardware and software, Purchased software, Software development, Consulting services, and Personnel training.

Evidently, IT input is a diverse group of products and services. Researchers must therefore use the aggregate monetary value of such services for each sampled business (or industry) that they include in the study. The problem of using monetary values surfaces again. A computer that cost $2000 five years ago provided one tenth of the computing power (speed, internal memory, etc.) of a computer that can be purchased today for half the price.

Even if we are willing to use nominal values of IT expenditures, we still face a formidable challenge. Obtaining such figures soon proves to be practically impossible. Few companies or industries in the U.S. or elsewhere maintain expense accounting along the above items. One surrogate, or proxy, variable for IT expense can be a company's total annual budget for IT. Again, obtaining such figures is extremely difficult, if not impossible. One reason is that many companies regard their investment in IT as confidential. Another reason is that the figures are not readily available; some of the costs are buried under non-IT accounting or budget line items.

## 9. The Issue of Quality

Several economists have noted that measuring only productivity gains of new technologies distorts the picture. Even if we do not gain more output, the output of new technology may be better than that of older technology. When using IT we increase not only the output of products and services, but also their quality. The products are more durable, their mean time between failures (MTBF) is longer, and they have some qualities that their predecessors did not. For example, it would be foolish to compare a 2001 car with a 1930 car. Thus, to calculate the benefits of car manufacturing technologies we must not only measure how many more cars we can produce now per day than we could produce with 1930 technology, but also the difference in quality.

The same approach is true when measuring the contribution of IT. But how do you calculate quality? Apparently, it is not easy. There are simply too many intangible elements to quality. Improvement in quality is another reason why one should be judicious when picking a firm sample to study output longitudinally. Since comparing output with different quality does not yield a true picture, researchers can select firms from an industry where the output has stayed stable in quality over years. Such industries include oil, utilities, and lumber companies. A barrel of oil is a barrel of oil, and a kilowatt-hour of electric power is a kilowatt-hour of electric power; similarly, a cubic foot of lumber is a cubic foot of lumber.

## 10. A Simple Theory

Despite the ongoing debate over the IT productivity paradox, companies continue to invest in IT. It is doubtful that executives would risk their careers and continue to make such investments year after year had they not noticed that IT adds some value to their organization. (Note that we say *value*, because value may not necessarily be in the form of productivity gains.) Thus, at least at the microeconomic level, perhaps "the proof is in the pudding."

Interestingly, economic historians have more modest expectations from new technology than other economists and IT researchers. Like economists, they are less interested in productivity at the firm level and more in the macroeconomic measure of productivity. However, they take a longer view of developments.

David [15, 16] compares the seemingly insignificant productivity gains of computers to those of electrical power in the U.S. in the years 1899-1920 when the dynamo spread. He explains the slow incremental productivity gains attributed to electricity with the long time it took business to adopt electrical power. He argues that the spread of computers has been similarly slow. In fact, the diffusion of IT has been significantly faster than that of electricity, especially thanks to the tremendous improvement of computing power and its falling prices [42]. Yet, while economists measured significant productivity increases in individual firms, their measurement of productivity gains from either technology has been mixed at the macroeconomic level.

Gordon [20] observes that despite the list of innovations during the first industrial revolution of 1760-1830, little productivity gains have been measured. If we are to judge by recorded productivity figures, the steam engine, the power loom, and other great inventions of the era affected productivity that grew extremely slowly in the 19$^{th}$ century. (However, he also observed that the second industrial revolution of 1860-1900, in which the electric and internal combustion engines were invented, led to measured productivity growth from 1913 to 1972.)

The discrepancy between significant contribution to productivity by IT at the firm level and the lack of contribution or insignificant contribution at the macroeconomic level combined with the above historic analogies prompt us to suggest a model that may reflect these explanations of "lack of productivity statistics." Our model also explains the oft-cited discrepancies between macro- and microeconomic observations of IT productivity: the lack of measured productivity in macroeconomic IT-related productivity at once along with positive microeconomic IT productivity.

One only has to observe the contribution of any technology to conclude that we might have exerted much energy to prove what, perhaps, cannot be proven. Our proposed model of what happens with productivity growth of new technologies draws on century-old observations. While it may be possible to measure the contribution of a specific technology to productivity gains at individual firms when the technology is not yet widespread, and while it has been shown that investment in a specific new technology can give early adopters strategic advantages, it may be a daunting task to measure productivity gains attributed to technologies that have matured and are now widespread.

Figure 1 illustrates what seems to happen when a new useful technology is adopted. The theory may explain what happens every time a new type of IT (such as new hardware or a new application) is introduced.

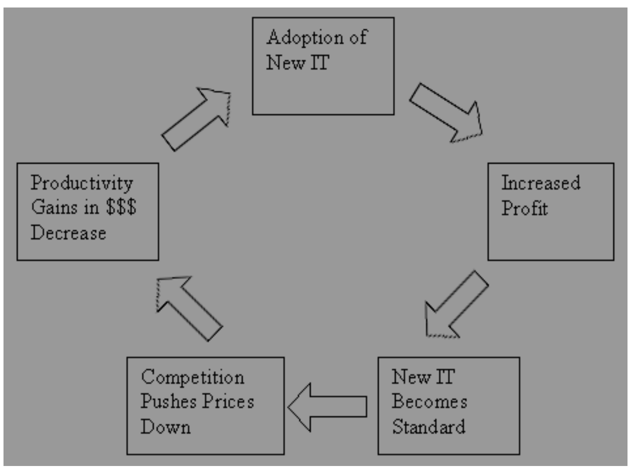


Figure 1
The IT Productivity Cycle

## 11. Phase 1: Adoption of IT

In this phase, a firm or a small number of firms adopt a new information technology: an innovative piece of hardware, a software application, or a method of using an existing IT. In some cases it is the adopter who was also the developer of the IT, in which case the long-term potential for first mover benefits is greater than if the technology was developed by a third party that convinces several competitors to adopt it. The technology either supplants existing technologies to more efficiently produce the same products or services, or enables adopters to produce new products or services. Adopters may enjoy significant increase in productivity.

## 12. Phase 2: Increased Profit

Some of the adopters of new IT experience the "bleeding edge." Their investment in cutting edge technology does not yield productivity gains and resulting profits because of adjusting difficulties. They lose money. However, other companies experience increase in profit, especially if the technology is proprietary and cannot be easily copied. Still, much of the adopted IT can be acquired by competitors. All the firms that use the technology experience increased productivity. They can produce more units of their products and services with the technology than without it. DosSantos and Peffers [18] proved that in the banking industry, first movers who invested in ATMs in 1972-1974 enjoyed increased market share and increased income; however, banks that invested in the same technology after that period did not enjoy such benefits.

## 13. Phase 3: New Becomes Standard

To stay competitive, all firms in an industry must adopt the technology. It gradually (or sometimes, quickly) becomes standard. The technology matured: companies are comfortable using it because their employees are skilled enough to use it, and it is widely available either through emulation or because it is offered for sale to all by the developers. Standard technology is any equipment and application used by a large majority of firms for daily operations. The technology is now ubiquitous. Firms simply cannot survive without it. In the banking industry, for instance, all banks ended up adopting ATM technology. As of the late 1970s, the technology has become standard and necessary for any bank to do business with individual clients.

Examples of other matured information technologies that have become standard applications include Web-based transaction systems and Web-search engines, now used by virtually all firms doing business through the Web. Information technologies that are maturing and will become standard include supply chain management (SCM) systems.

## 14. Phase 4: Decreased Prices

Firms transform much of their productivity gains into price cuts. They can now afford to offer their products and services for lower prices because, thanks to the technology, the production cost per unit is lower. Since the technology matured and has become standard, for the majority of firms the investment in the technology now may not result in economic gains. In fact, some firms may lose money despite their adoption of IT. Companies that have not adopted the technology are at a clear disadvantage.

## 15. Phase 5: Productivity "Disappears"

If firms measure their productivity gains in dollars, they may find that IT did not contribute any productivity growth. The number of sales dollars may actually be fewer than those before the IT adoption, simply because the price of each unit sold has decreased so much. This is the nominal picture at the individual firm. However, productivity has increased: the firm now produces more (significantly cheaper) units of its products and services. At the macroeconomic level, inadequate GDP deflators and other deflators may be too inaccurate in helping reflect the true gains in productivity. As Griliches [21] notes, mismeasurement of output occurs mainly in industries where IT is used most, such as banking, insurance, and business services. One could add another product that for years was not included in the GDP statistics: software. For many years software was considered an intermediate good, unlike the final goods whose figures are included in GDP statistics. Software is produced with the aid of IT. Anyone who has worked as a programmer for the past decade would recognize the huge leap in productivity gains over the years in the production of software.

Interestingly, one study that did not purport to measure labor productivity per se produced evidence that IT has increased labor productivity. Brynjolfsson, Malone, Gurbaxani, and Kambil [8] found that as U.S. firms increased their investment in computers, the size of firms has decreased. Smaller companies may indicate productivity gains: firms can produce their planned quantities at desired quality with fewer workers. The researchers considered only hardware as their IT input. They accounted for the lag in time it takes firms to adjust to the new technology, namely for the technology to mature. Apparently, the technology has produced labor productivity gains at the macroeconomic level. At the same time, we might find it difficult to see any measurable productivity at individual firms that were established a short time before the study period. These companies were established with a smaller labor force than would be needed to produce the same output several years earlier.

When a certain information technology matures and becomes standard, asking "why do we lose money although we use IT?" is akin to asking "why do we lose money although we use telephone and fax?" Companies that were the first to use telephones might have been more competitive for a while, until telephones became standard business equipment everywhere. One need only read about cases of strategic information systems to understand that only proprietary IT, which cannot easily be acquired or emulated, can give firms competitive advantages that are reflected in increased profit. But, again, profit may have nothing to do with productivity. A firm may be profitable and not very productive (because technology helps it sell something that its competitors cannot sell); or the firm may actually lose money but be more productive than it was a year ago (because now it uses IT that enables it to make more units with less labor).

## 16. Distinguishing Between Productivity and Strategy

Phase 2 of the proposed model highlights an important distinction between pursuing productivity in general and implementing strategic investment in IT. Often, investment in IT has yielded great strategic benefits, such as increased market share, significant reduction of business cycle time, and products of superior quality. For example, DosSantos and Peffers [18] conducted a large-scale study of banks and proved that early adopters of ATM technology increased market share and income. One only needs to examine the highly publicized cases of American Airline's Saber reservation system, McKesson's Economost order fulfillment system, Cisco Systems' supply chain management systems, and Amazon.com's Web-based transaction systems to realize that IT can and has yielded great competitive advantages.

A model developed by Barua, Kriebel, and Mukhopadhyay [3] proves that under certain assumptions, a competitor in a duopoly will reap productivity gains and economic profit from being the first to use IT. And, indeed, in many cases the strategic advantage emanated from increased efficiencies of labor and other resources which were now greatly supported and enhanced by the introduction and integration of IT into business processes. However, there is a difference between strategic advantage and productivity.

## 17. Suggestions for Further Research

Can we improve the measurement of IT contribution to labor productivity? We would like to offer an approach. What businesses really want to know is whether they can increase production with the same or smaller number of employees as a result of acquiring IT. Thus, the important factors to measure are labor productivity and the contribution of IT to this productivity. Measuring marginal product is a valid approach to measurement of the contribution of a specific input relative to all other inputs, but it does not tell us much about the rate of contribution of the specific input to overall output, which has been the greater concern of most researchers. More specifically, the main interest is measuring the contribution of IT to gains of labor productivity [1]. The equation in measuring such gains is:

$$\Delta LP = \beta_0 + \beta_1(IT) + \beta_2(Cap)$$

Where:

IT = Information technology expenditures (adjusted for price changes) including telecommunications, software, hardware, and services, spent in the years *n-d* to *n+t-d*, inclusive

Cap = Total non-IT capital expenditures from year *n* to year *n+t*, inclusive

LP = Labor Productivity

And where

$$LP = \frac{\text{Physical output (in units)}}{\text{Number of Employees (or number of labor hours weighted by hourly wage)}}$$

and $\Delta LP = LP_{n+t} - LP_n$

It takes several years for an investment in IT to have an impact on the output of a business. Let us term this number of years *d*. While Cap is measured as the cumulative values of this variable between year *n+t* and year *n*, IT is measured as the cumulative value of IT between year *n+t-d* and year *n-d*. This last condition is due to the time it takes the IT investment to yield fruit due to training and adjustment. The time lag *d* may differ across industries. For example, Allen [1] argues that *d* is five years in the electricity utility industry.

Ideally, IT would be expressed as several components of real input units, and, therefore, as several independent variables. However, this is practically impossible because IT consists of numerous different types of hardware, of software, of telecommunications equipment and software, and of in-house and purchased services.

The figures must be dollar amounts invested in each of the above IT inputs (hardware, software, etc.) deflated to the base year. This may be a daunting task because there are no reliable statistics from which such deflators could be extracted, let alone the fact that the quality of hardware, software, and other IT inputs has increased over the years. Again, as with output quality, we have the issue of input quality. Comparing 2002 hardware and software with 1995 hardware and software are akin to comparing apples and oranges. A 2.2GHz computer is not the same machine as a 333 MHz computer, and an ERP system is not the same as a bunch of disparate applications, even if the new hardware and software cost the same as the old hardware and software in real (deflated) dollars.

Since Cap comprises an investment in a myriad of capital equipment and services, using physical units is impractical, even more so than estimating IT.

Had we been able to collect the data for the above variables, we could run a multiple regression analysis and calculate the betas. The most important beta, $\beta_1$, would tell us how much IT investments contributed to labor productivity between the years *n* and *n+t*. However, as mentioned before, obtaining data appropriate for this analysis is practically impossible. In one attempt [31], the researchers succeeded in collecting data on 12 years of trucking in the U.S. As mentioned above, output in this industry can relatively easily be measured in real units: truckload (TL) miles and less-than-truckload (LTL) miles. Several thousand dollars were spent on the data and its adjustment for analysis. Difficulties emerged as soon as the researchers tried to collect data on investment in hardware, software, telecommunications, and IT services. Fewer than 25 of the sample's 1000 firms responded. An investigation revealed that in most companies, such data are not readily available.

Had researchers had access to such data, the answer to the question "Does IT make a significant contribution to labor productivity growth" could be definitive. The answer would be definitive because the analysis would inherently take into consideration all the factors that eventually contribute, directly and indirectly, to productivity: smaller inventories, shorter cycles, greater employee satisfaction, and many other factors that IT has been credited with improving.

## 18. Conclusion

By and large, the studies of IT productivity have produced inconclusive results. They have not provided unequivocal conclusions either at the firm level or at the national economy level. However, since the evidence around us is that businesses do use IT and have steadily continued to invest in IT, on average, more than they have invested in any other type of means of production since the late 1970s, economists and IT researchers are still in pursuit of a clear answer to the question: is the contribution of IT to productivity significant?

We have enumerated the difficulties in measuring productivity gains attributed to IT. We have highlighted the inaccuracy of measuring firm productivity in profitability terms and economic productivity in dollar terms. Productivity can be accurately measured only in real terms: gain in real output units per real unit of input, in this case – a unit of IT. While measuring real output units is possible in some manufacturing industries and fewer service industries, it is impractical to use real units of IT, mainly because IT consists of many different means of production – hardware, software, telecommunications, and services – and because it is difficult to obtain reliable data on IT investment from corporations. Inaccurate measurement and difficulties in access to appropriate data may continue to hamper the hard work of IT productivity researchers.

One piece of information that has been sorely missed in this pursuit is a definition of a basket of IT resources and its pricing. If government agencies (such as the U.S. Bureau of Economic Analysis) defined such a basket and tracks its price in a similar manner it does with a consumer basket, researchers could more comfortably consider the contribution of IT to labor (and multifactor) productivity.

However, even with a reliable "IT Price Index," we may not be able to reach a definitive conclusion on the contribution of the "IT basket" to productivity. One important observation that researchers have made is the significant difference between IT and other technologies. IT helps to fundamentally change business processes and the relationships between firms and suppliers and firms and customers. The economic contribution of such fundamental changes, too, is not accounted for in most IT productivity studies.

Corporate boards of directors have long given up the attempt to receive a detailed return on investment (ROI) calculation for every investment in IT. They understand that such ROI is too often infeasible. They approve such investments because they know that intangible benefits such as better decision-making and employee satisfaction will increase productivity. If the purpose is to calculate the exact contribution of IT, as a family of technologies, to productivity gains in a specific firm, industry, or sector, perhaps this stream of research should continue. But if the purpose is to convince anyone that IT, as a family of technologies, contributes to productivity, further research may not be worth the effort. Society seems to be convinced.

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