Information Technology and Economic Performance: A Critical Review of the Empirical Evidence

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For many years, there has been considerable debate about whether the IT revolution was paying off in higher productivity. Studies in the 1980s found no connection between IT investment and productivity in the U.S. economy, a situation referred to as the *productivity paradox*. Since then, a decade of studies at the firm and country level has consistently shown that the impact of IT investment on labor productivity and economic growth is significant and positive. This article critically reviews the published research, more than 50 articles, on computers and productivity. It develops a general framework for classifying the research, which facilitates identifying what we know, how well we know it, and what we do not know. The framework enables us to systematically organize, synthesize, and evaluate the empirical evidence and to identify both limitations in existing research and data and substantive areas for future research.

The review concludes that the productivity paradox as first formulated has been effectively refuted. At both the firm and the country level, greater investment in IT is associated with greater productivity growth. At the firm level, the review further concludes that the wide range of performance of IT investments among different organizations can be explained by complementary investments in organizational capital such as decentralized decision-making systems, job training, and business process redesign. IT is not simply a tool for automating existing processes, but is more importantly an enabler of organizational changes that can lead to additional productivity gains.

In mid-2000, IT capital investment began to fall sharply due to slowing economic growth, the collapse of many Internet-related firms, and reductions in IT spending by other firms facing fewer competitive pressures from Internet firms. This reduction in IT investment has had devastating effects on the IT-producing sector, and may lead to slower economic and productivity growth in the U.S. economy. While the turmoil in the technology sector has been unsettling to investors and executives alike, this review shows that it should not overshadow the fundamental changes that have occurred as a result of firms' investments in IT. Notwithstanding the demise of many Internet-related companies, the returns to IT investment are real, and innovative companies continue to lead the way.

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1. INTRODUCTION

"You can see the computer age everywhere but in the productivity statistics."

[Solow 1987].

"Despite differences in methodology and data sources, a consensus is building that the remarkable behavior of IT prices provides the key to the surge in economic growth."

[Jorgenson 2001].

1.1. Background

There has been a long-running debate in the business press and the information systems and economics literature over whether the information technology (IT) revolution is paying off in higher productivity. The first studies, conducted in the 1980s, found no connection between IT investment and productivity at the level of firms, industries, or the economy as a whole [Loveman 1994; Roach 1987, 1989, 1991; Strassmann 1990]. Skeptics pointed out that heavy IT investment had occurred concurrently with the productivity slowdown that began in 1973 in the U.S.

This so-called *productivity paradox* stimulated economists, management scientists, and information systems researchers to conduct more rigorous scientific analyses of the relationship between IT and productivity [Brynjolfsson 1993, 1996; Bresnahan 1999; Brynjolfsson and Hitt 1995, 1996, 1998; Oliner and Sichel 2000; Jorgenson 2001; Jorgenson and Stiroh 2000; Bosworth and Triplett 2000; Council of Economic Advisers (CEA) 2001]. These studies, which used larger datasets and more refined research methods, revealed positive and significant impacts from IT investments at the firm and country level. Moreover, some of these studies showed that the economic boom and surge in productivity of the late 1990s was largely due to heavy investment in IT and the growth of the Internet.

The debate over IT and productivity then shifted to whether the IT-led economy would lead to permanent improvement in the prospects for economic growth, or whether it was a temporary phenomenon, with much of the acceleration in productivity driven by the business cycle and concentrated in just a few sectors of the economy, a point of view espoused by Gordon [2000].

Given the continuing debate about whether IT investments pay off, this research review critically evaluates the large body of evidence-based research on the subject. The purpose is to critically survey the published research on IT and economic performance to determine what we know and what we do not know about the returns to IT investments. The goal is to help direct future research into potentially productive channels so that it can contribute to knowledge about whether or not, as well as how, IT investments can be effectively introduced and managed for greater payoffs.

Specifically, the aim of this article is to (1) organize and integrate the research on returns to IT investment in a way that adds understanding to work in the area, (2) provide an unbiased and objective view of the documented returns (or lack of returns) to IT investment at three levels of analysis—firm, industry, and country, (3) identify the factors that contribute to payoffs from these investments, (4) evaluate issues in current research, and (5) identify opportunities for future research. It is intended that this review will help readers to understand this important area of research, stimulate experts to deal with unresolved issues in ongoing and future research, and assist senior executives in future decision-making about IT investments in their organizations.

We begin with a discussion of the scope of the literature reviewed and the organization of this article.

1.2. Scope of Literature Review

This review examines more than 50 empirical studies based on economic analysis that have appeared between 1985 and 2002.[1] Early studies were based on

[1] There is other writing on the subject that is not part of this review. For example, Laudon and Marr [1994] brought political perspectives to bear on understanding the productivity paradox when they argued that productivity returns from IT investment might not

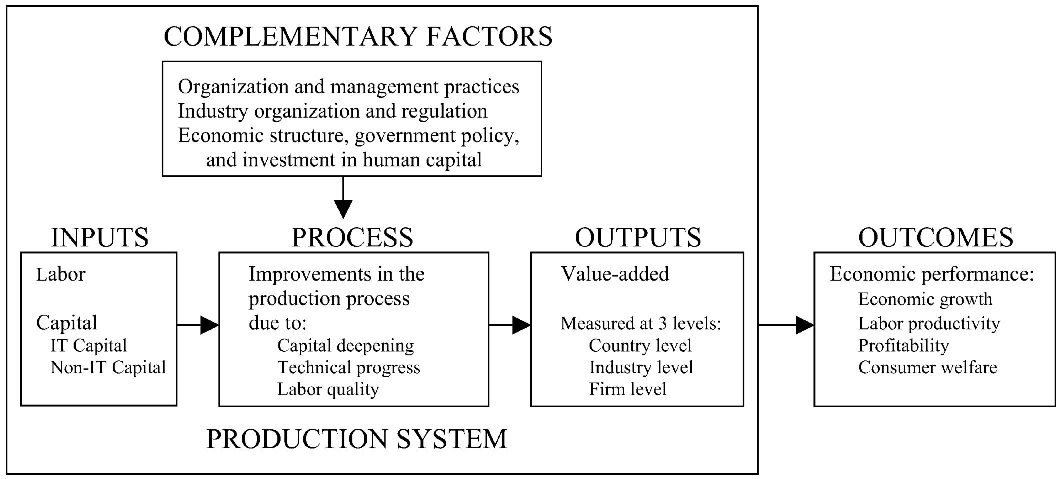

Fig. 1. IT and economic performance—framework for literature review.

small samples and limited data, whereas recent studies have been able to take advantage of both better data and larger samples, including time-series data. The review concentrates mainly on studies whose results have been published in peer-reviewed scholarly journals such as *American Economic Review, Communications of the ACM, Information Systems Research, Journal of Economic Perspectives, Journal of Management Information Systems, Management Science, MIS Quarterly, Organization Science, Quarterly Journal of Economics, The Information Society, The Brookings Papers*, and *World Development*. These journals are known for having high standards for review and acceptance and therefore are most appropriate for a critical review that seeks to achieve an objective and balanced perspective on the research. The review also includes a few other works because of their significance or because they help to round out the research in an area. Finally, Brynjolfsson [1993] and Brynjolfsson and Yang [1996] have provided excellent reviews of earlier research.

even be an objective in the macroculture of some organizations. Similarly David [1990] and King [1996] brought historical perspectives to the IT and productivity debate.

1.3. Organization of this Review

The review is organized as follows. Section 2 introduces a conceptual framework for thinking about IT and economic performance. Sections 3 through 5 assess the literature at three levels of analysis: firm, industry, and country. Section 6 presents both substantive and methodological issues that need to be addressed in future research, and Section 7 presents specific, high-priority recommendations for future research based upon key deficits in the current body of knowledge. Finally, Section 8 discusses limitations of the survey and highlights some major conclusions.

2. CONCEPTUAL FRAMEWORK

In order to organize the prior research and to identify gaps for future efforts, we developed a conceptual framework (see Figure 1) that allows us to map and assess the research findings. The framework helps to define the key variables and relationships addressed in the different research studies reviewed herein. Moving from left to right in Figure 1, the framework identifies the various inputs (labor and capital) to the production process and complementary factors of production that influence the production process, and enables an assessment of the contribution of those inputs to outputs (value added, gross domestic product) and to various outcomes (economic growth, labor productivity, profitability, and consumer surplus). It further distinguishes between firm, industry, and country levels of analysis. We begin our presentation of the framework by defining the key terms in the title of this review—IT investment and economic performance.

2.1. Definition of IT Investment

Traditional economic studies of productivity focused on capital such as plants and equipment using aggregate measures of capital that include all its component categories. In studies of IT and productivity, it becomes necessary to disaggregate capital into the component categories of investment—IT and the traditional forms of capital, labeled non-IT. IT investment, broadly defined, includes investments in both computers and telecommunications, and in related hardware, software, and services. However, as operationally defined in nearly all of the research included in this review, IT investment is limited mainly to computer hardware. In most studies, investment is defined as an annualized value of the stock of computer investments including the depreciated value of previous investments that are still in service, or as annual spending.

2.2. Definition of Economic Performance

Economic performance can be interpreted in a variety of ways at each level of analysis. At the country level, where much of the debate has occurred, it usually refers to economic growth, labor productivity growth, and consumer welfare (Figure 1). *Economic growth* is the rate of change in real output, or GDP, and is measured at the country level. Labor *productivity growth*, or growth in output per worker, is a measure of the efficient use of resources to create value. It “allows the economy to provide lower-cost goods and services relative to the income of domestic consumers, and to compete for customers in international markets” [McKinsey Global Institute 2001, p. 1]. Corresponding measures focusing on the output of an industry sector are utilized at the industry level.

Clearly, labor productivity growth is also an indicator of the economic performance of firms. A firm that is more productive than its competitors will generally enjoy higher *profitability*, which is of course, also an important measure of economic performance for firms. A more productive firm will either produce the same output with fewer inputs and thus experience a cost advantage, or produce higher-quality output with the same inputs, enabling a price premium. However, as will be discussed later in the review in regard to firm-level research, competition induces other firms to catch up in productivity. Sustaining higher profits through productivity gains requires a firm to maintain productivity levels higher than its competitors. Therefore, over time, profits might be competed away with the result that consumers benefit. This benefit is measured as consumer surplus and refers to the aggregate value realized by consumers from their purchase of a good less the price paid.

2.3. Modeling the Production Process

In order to better understand the IT and productivity debate, it is useful to begin with a discussion of the production process by which inputs are transformed into outputs in firms and economies, and the specific role of IT as a factor of production. Economists use two related approaches to modeling the production process by which inputs are transformed into outputs. One approach to understanding the output of an economic system is production economics, which uses specific functional forms, called *production functions*, to model the production process [Bresnahan 1999; Brynjolfsson and Hitt 2000]. This approach uses econometric techniques to relate the output of a firm, industry, or economy to the inputs based on estimation models derived from the production function. Inputs typically accounted for in this approach include labor and capital, including both IT and non-IT capital. Most of the studies at the firm level use this approach. The primary approach used to model the production process inherent in an economy (or industry) is growth accounting [Oliner and Sichel 2000; Jorgenson and Stiroh 1999, 2000; Council of Economic Advisors 2001]. This method also assumes specific properties of the production process and, based on these assumptions, allocates shares of output to the various inputs to production.

Output growth in firms, industries, and the economy may arise from increases in input levels, improvement in the quality of inputs, and growth in the productivity of inputs. The focus of the literature reviewed here has been on understanding how increased levels of investment in IT impacts labor productivity. First, labor productivity can increase when workers are provided with more capital, a phenomenon called *capital deepening*. Second, technical progress in the production process or in the quality of output can increase the level of output without additional investment in input, a phenomenon labeled *multifactor productivity* (MFP). An increase in MFP means that for a fixed level and quality of inputs, a firm, industry or economy is achieving higher levels of output. This form of productivity improvement is of great importance because it reflects structural gains that are permanent.

The framework also posits that there are complementary factors that influence the payoff from IT investments (Figure 1). At the firm level, these include organization and management practices [Brynjolfsson 1996; Bresnahan et al. 2002; Brynjolfsson et al. 2000]; at the industry level, they include industry organization [Melville 2001]; and at the national level, they might include economic structure, government policy, and investment in human capital [Dewan and Kraemer 2000]. The following discussions elaborate the framework for each level of analysis. Indeed, as we shall see below, it is these complementary factors that have been suggested as helping to explain some of the extraordinary estimates of returns to IT investments.

The analysis that results from these approaches indicates the relative contribution of labor and capital to output, and the relative contribution of the different drivers of labor productivity growth, as illustrated in Figure 1 above. As will be seen later, the assumptions that various researchers make in doing the analysis can have substantial impacts on the results and implications.

2.4. Role of IT in the Production Process

Much of the debate among economists has addressed these economic performance issues in the aggregate, at the country and industry levels. Yet, the decision makers who choose to invest in IT are managers who deploy IT for use in their organizations and who use investment criteria that are related to the outcomes at the level of the firm. While labor productivity is certainly one often-used criterion, managers also use measures such as profitability, market share, margins, and product variety and quality as justifications for investment in IT systems.

In order to understand the overall impact of IT at the firm level, it is useful to begin by thinking about the qualitative impacts of introducing IT into a firm's production processes. Past research has distinguished between using IT to automate processes, to provide better information, and to transform entire processes [Zuboff 1988]. The impact of automation is primarily the direct substitution of capital for labor, consistent with capital deepening. For example, a cashier at a retail chain store using a computer-based information system such as a scanner can process a transaction in less time. The impact of improved information is that it allows workers and managers to make decisions more effectively. For example, information provided by the store-based system allows the managers to better manage inventory. Transformation impacts occur when a firm redesigns a process to achieve significantly higher levels of productivity. In our example, the firm may redesign its supply chain using a supply chain management system, of which the store system is a key element.

One key difference between IT capital and other forms of capital is the dual roles that IT can play in a firm. First, like other types of capital, IT can be used directly as a production technology to improve labor productivity, as in the case of a bank's transaction processing system. However, research suggests IT has its greatest impact in its second role as a technology for coordination [Bresnahan 1997; Gurbaxani and Whang 1991; Malone et al. 1989]. In this literature, IT is viewed as an especially potent technology that has a significant impact on the costs of coordinating economic activity both within and between organizations. Research in this arena suggests that the unique value of IT is that it enables fundamental changes in business processes and organizational structures that can enhance MFP.

2.5. The Aggregate Impact of IT

While IT is deployed at the level of the firm, the analysis of the impact of IT at the level of an industry or the economy allows researchers to answer a related but different set of questions that are of critical importance. At the level of the economy, it furthers an understanding of the role of IT and the IT sector in fostering economic growth and, ultimately, the wealth of a country. It also facilitates a discussion of whether steady-state growth rates are higher in an IT-intensive economy. It enables the documentation and understanding of industry differences, and an examination of the role of industry characteristics such as structure and regulation in moderating the returns to IT investment.

While IT can increase productivity via capital deepening and via MFP growth, the results might be substantially different in different industry sectors. In particular, an important distinction has to be made between the IT-producing and IT-using sectors. The IT-producing sectors are those which manufacture semiconductor, computer, or telecommunications hardware or provide software and services that enable these technologies to be used effectively in organizations. The IT-using sectors are all the other sectors of the economy that apply IT as part of their operations in order to achieve greater efficiency and effectiveness. They include sectors such as manufacturing (durable[2] and nondurable), wholesale and retail trade, finance, insurance and real estate, business and professional services, and so on. As we shall see below, there is no question that there have been very rapid improvements in productivity and in MFP in the IT-producing industries, particularly in computer hardware and components as a result of research and development on product and process technologies.

A critical question is whether there have been similar gains in productivity and MFP outside the IT-producing industry and, if so, whether those gains can be attributed to investment in IT capital. Has the use of IT allowed industries to achieve superior production methods than were previously unavailable? Put differently, are there spillovers from IT-producing industries to IT-using industries?

2.6. Implications for this Review

As the foregoing suggests, a comprehensive review of the payoffs from IT investment must examine the returns to this investment at the *disaggregate level* of the firm as well as the *aggregate level* of industries and the economy since the nature of the payoffs at these levels may be quite different. If IT investments are increasing productivity at the firm level, it might be the case that in the aggregate they will also increase the productivity of entire industries and countries. However, it is possible that gains will show up at one level and not the other, depending on whether individual firms capture the returns on their investment, or whether some or all of the gains are competed away and flow to consumers, creating social benefits but not providing a measurable return to the firms making the investment. Furthermore, in addition to firm-specific factors, industry characteristics

[2] Ordinarily, durable goods manufacturing includes the IT-producing sector.

also affect the payoffs that firms within an industry receive from their IT investments and how these payoffs are shared between firms. It is therefore important to examine the results at both disaggregate and aggregate levels.

In order to understand whether IT investment results in greater productivity, we next look systematically at the research on the returns from IT investments for each level of analysis—firm, industry and country—in that order. We examine the research as a basis for understanding the nature, extent, and limitations of payoffs from IT investments. We review the evidence provided by numerous systematic, empirical studies. We summarize some of the major studies in the Appendix and Tables I and II.

3. FIRM-LEVEL RESEARCH

While the productivity paradox as originally framed focused on aggregate country-level productivity statistics, actual IT investments are made by organizations, mostly firms, that are interested in their own return on investment, not that of the country as a whole. Knowing that IT investment improves aggregate productivity does not imply that individual firms enjoy similar benefits. In fact, there may be significant social benefits from IT investments that increase consumer welfare but are not captured by the firms making those investments. Therefore, it is of great concern to business and technology executives whether their IT investments are paying off at the level of the firm.

3.1. IT and Firm-Level Productivity

Motivated by the productivity paradox, many firm-level studies were launched in the 1980s and 1990s. Early studies were unable to show that IT investments led to payoffs, in most cases because of inadequate data on IT investments and small sample sizes [Brynjolfsson and Hitt 1996, 2000; Brynjolfsson and Yang 1996]. Most discouraging were several studies of service firms, such as banks and insurance firms, which showed weak or nonexistent links between IT and productivity, but where output measurement is notoriously difficult [Franke 1987; Strassmann 1990; Alpar and Kim 1991; Harris and Katz 1991]. Some studies of manufacturing firms did show positive returns on IT investment, partly because it is easier to measure the output of manufacturing and adjust for improvements in quality [Weill 1992; Barua et al. 1995]. These studies began to highlight the importance of the accurate measurement of outputs, particularly in the technology-intensive service industries where the largest investments in IT capital were being made.

Starting around 1993, more rigorous studies with larger samples were being reported by researchers [Brynjolfsson 1993, 1996; Bresnahan 1999; Brynjolfsson and Hitt 1995, 1996, 1998; Lichtenberg 1995]. These studies involved large U.S. corporations, using data on IT capital investment from market research firms and from surveys of chief information officers and other executives, coupled with financial data from reliable sources. The research used econometric techniques based in production economics that relate firm output (measured as value added by a firm) to a set of inputs including labor hours, non-IT capital stock, and IT capital stock, and estimated the marginal product or output elasticity of IT capital.[3]

Each of these studies found that IT investments contribute to firm productivity, and show higher gross marginal returns than non-IT investments. The fact that these researchers found a strong relationship between IT capital and productivity that was not evident in earlier studies may partly reflect the fact that the data was more recent, that levels of IT investment had increased, making it easier to distinguish its contribution, and that over time firms were learning to apply IT capital more productively. They may also simply reflect better data sets and analytical tools that make it possible to isolate and measure the true impacts of IT investment.

[3] The output elasticity of IT is the increase in value added associated with a 1% increase in IT investment.

More recently, Brynjolfsson and Hitt [2000] have found that payoffs to IT investment occur not just in labor productivity increases but also in MFP growth, and that the impact on MFP growth is maximized after a lag of 4 to 7 years. Gilchrist et al. [2001], using the same dataset, focus on the manufacturing companies in the sample and show that IT has a substantial and contemporaneous impact on labor productivity growth and on MFP growth in the durable goods sector, which exceeds the impact that would be predicted by its factor share. They find that, in the nondurable goods sector, the returns to labor productivity accrue primarily via capital deepening, and are consistent with IT factor share. Moreover, these returns are correlated with decentralized computing architectures, suggesting that the diffusion and networking of computing throughout the organization contributes substantially to the payoff.

In addition to these U.S. studies, a few other studies have been conducted on firms in other countries. Greenan et al. [2001] analyzed data on French firms' IT investment and productivity and came to results consistent with the findings of Brynjolfsson and Hitt [1996] and Lichtenberg [1995] for U.S.-based firms. By contrast, Lal [2001] did not find a relationship between IT investment and productivity in Indian garment makers. This is consistent with the cross-country studies, which are discussed later [Dewan and Kraemer 2000; Pohjola 2001], that have found a strong relationship between IT and productivity in developed countries, but not in developing countries. With low unit costs of labor and higher capital costs, it is not surprising that there are fewer opportunities for capital-labor substitution in developing countries. Also, Lal's sample included many small and medium-sized firms, a group not included in most U.S. studies.

Most of the studies found that IT investments were associated with higher marginal product than other capital investments. These are translated into "excess returns" by some authors, who pointed out that, in theory, all investments should pay the same risk-adjusted return at the margin. These returns do need to be adjusted to account for the high rate of obsolescence of IT capital, so that the net returns are much lower. However, Brynjolfsson and Hitt [1996] and Lichtenberg [1995] found that after subtracting standard estimates of the cost associated with the obsolescence of IT capital of up to 42% per year from the gross returns, the net returns from IT were still higher than those of non-IT investments. These results of firm-level studies have sometimes been taken to imply that firms are systematically underinvesting in IT, given the high marginal returns to such investments.

Some answers have been proposed to this question in the literature and others will be suggested here, but we would warn that claims of systematic underinvestment in IT should be viewed cautiously. First, as Brynjolfsson and Hitt [2000] pointed out, the true cost of such investments may be underestimated. All studies include the direct investment in computer hardware; others attempt to include labor, software, and services, but it is difficult to estimate these with a high degree of precision. Importantly, they do not include the costs of complementary investments such as training and process reengineering that can be much larger than the actual direct investment in IT. If these costs are included on the investment side of the equation, the returns might look more modest. Moreover, taking into account the large standard deviations in the payoffs documented by many studies, it is possible that the net returns to IT investments are consistent with non-IT investments.

Given these caveats, it is still possible that IT investment does show higher than normal returns. There are several reasons why this could be so. IT investment might be riskier than other investment. Firms invest when the net return is sufficient to cover the risk-adjusted cost of capital. This would argue that returns need to be higher to compensate for the additional risk. Most studies do not assess the impact of the risk of these investments. Moreover, there might be adjustment costs. It is difficult and costly for firms to introduce new IT innovations. With decreasing prices for IT, the optimal level of IT investment and capital stock increases in steady state. However, firms face real costs and delays due to the duration of software development, retirement of older systems, and changes in practices that suggest that firms might not achieve these optimal levels in the short run. It is therefore difficult to conclude that the "excess returns" found in firm-level studies imply that firms are systematically underinvesting in IT, or that managers are acting irrationally.

This recent research also highlights other interesting questions that remain unresolved regarding the payoffs from investments in IT capital. First, it is not well understood why firms in different industries accrue different payoffs. For example, it would be valuable to identify the specific characteristics of durable goods manufacturing firms that enable them to achieve higher returns relative to nondurable goods manufacturing firms. Second, a better understanding of the timing of the payoff from investments in IT capital is also needed. Clearly, a firm's many individual investments in specific systems will have different periods over which the payoffs will be realized. Some systems will realize immediate payoffs, while others will realize payoffs after a lag. The duration over which the payoffs will be realized will also vary. Some will have short-term impacts and others will have longer-term impacts. This understanding will go a long way toward resolving the debate on whether the impacts of these investments are contemporaneous with the investiments or occur in the future.

3.2. Variance Among Individual Firms

The preponderance of evidence points to positive and significant returns to IT investment among firms. Clearly, higher levels of IT investment are associated with higher levels of productivity across a large sample of companies, and this has been true since the mid-1980s at least. However, looking at a scatter plot of IT investment and productivity, as Brynjolfsson and Hitt [1995, 1996] have presented in several of their papers, one is struck by how widely scattered the actual data points are around the trend line. This leads to the next major finding in the firm-level data.

The productivity impacts of IT investments vary widely among different companies.[4] In other words, some firms use IT much more productively than others. Brynjolfsson and Hitt [1995] estimated that these "firm effects" may account for as much as half of the productivity benefits attributed to IT investment in their earlier work, but stated that the elasticity of IT remains positive and significant even after firm effects are taken into account. Still, this raises the question of what causes these firm effects.

Two factors stand out. First, there are idiosyncratic firm characteristics such as market position, rigidities in cost structures (e.g., labor contracts), brand recognition, or the vision and leadership abilities of key executives, which affect a firm's strategic options and therefore its potential to derive benefits from IT investment. These can change over time, but are not easily manipulated by management in the short run.

Second, there are specific features of organizational structure, strategy, and management practices that can be compared systematically across companies. The management of a firm, through restructuring, new management control systems, the redesign of processes, or by upgrading employee training, can directly influence these features.

3.3. Impact of Business Practices on Value of IT Investments

Management practices and complementary investments explain part of the variation in IT payoffs. Loveman's [1994] early analysis of manufacturing firms, which found evidence of net marginal benefit for non-IT investments but not for IT investments, highlighted complementary

[4] The variance of returns to IT capital is larger than the variance of returns to non-IT capital.

organizational factors as a possible explanation for the research results. He argued that the evidence could be interpreted as management failure to effectively integrate IT with the firm's business strategy, human resource management strategy, and efficient resource allocation. That is, management did not implement the organizational changes that should accompany IT investment in order to create value.

Subsequent studies at the firm level explicitly show that the value of IT investments is substantially impacted by the structure and business practices of the firms making the investment. For instance, Weill [1992] showed that the quality of a firm's management and its commitment to IT enhances the contribution of IT investments to firm performance. Francalanci and Galal [1998] showed that firms with a higher proportion of information workers gain more from their IT investments than those with a lower proportion. Tallon et al. [2000] found that aligning IT with business strategy increased the payoffs from IT investments. In addition, firms with higher levels of investment gained greater payoffs from alignment. Devaraj and Kohli [2000] found that business process reengineering enhanced the payoffs in firms that also made greater IT investments. Ramirez et al. [2001] found that organizations which invested more in IT and implemented management practices such as employee involvement and total quality management received higher IT returns.

Black and Lynch [1997] studied the impacts of workplace practices, IT capital, and human capital development on productivity. They found that what affected productivity was less the presence or absence of a particular management practice, such as total quality management, than the way in which the practice was implemented. Particularly important was employee involvement—for instance, the proportion of workers involved in regular decision-making in a plant.

In addition to these studies of individual management practices, Brynjolfsson and Hitt [2000] and Bresnahan et al. [2002] showed that firms with a cluster of management practices, including decentralized decision-making (which they called *organizational capital*) along with high levels of IT investments, outperform all others. Interestingly, firms with traditional centralized organizations and high IT investments actually do worse than similar organizations that invest less in IT.

While the evidence shows the benefits of certain classes of management practices, these can be difficult to translate into specific actions for individual companies. It is logical that executives and managers can improve the performance of their IT investments by combining these investments with proven complementary managerial practices. However, the research evidence is limited as to specific links between management practices and productivity. In particular, understanding the relationship between firm-specific factors and management practices is critical and by definition cannot be addressed in large-sample studies. For instance, the fact that decentralized firms earn higher returns to their IT investments than centralized firms on average is not sufficient to advise a particular firm to switch from a centralized structure to a decentralized one. Given the firm's idiosyncratic characteristics, a centralized structure might be more appropriate.

3.4. IT and Firm Financial Performance

There is mixed evidence at the firm level as to the impacts of IT capital on financial performance measures such as profitability or market value, partly because the linkage is less direct. While IT investments can directly affect a firm's output and many operational indicators (e.g., inventory turnover, plant productivity, product quality), a firm's financial performance is determined by a wider range of strategic and competitive factors that go beyond productivity.

Several studies show a relationship between IT investment and intermediate measures of operational performance. Barua et al. [1995] found that IT investment affects intermediate measures such as inventory turnover but found no evidence that the benefits extended to firm performance as measured by return on assets. Srinivasan et al. [1994] found that EDI technology at Chrysler benefited suppliers and buyers due to improved accuracy and precision of materials management information, thereby reducing shipment discrepancies by over 50% within 2,700 shipments across 193 suppliers. Similarly, Mukhopadhyay et al. [1995] found that a materials management system at Chrysler reduced the costs associated with inventory holding, obsolescence of inventory, and transportation. Finally, Banker et al. [1990] found that a point-of-sale and order coordination system in the Hardee's restaurant chain enabled managers to reduce materials waste and improve store sales.

However, early efforts to relate IT investment to financial performance have had mixed results. Brynjolfsson and Yang [1997] found that a dollar of computer capital was associated with between $5 and $20 (depending on assumptions in the models) in additional market capitalization for public companies, pointing to a link between IT and financial valuation. The authors interpreted this finding as evidence of important but unmeasured complementary organizational practices, or intangible assets, that are not included in the accounting of firm-level investment, and not as evidence of IT investment resulting in an increase in market capitalization. Brynjolfsson et al. [2000] found that when organizational capital is included in the analysis (i.e., the cluster of complementary practices mentioned previously), it increases market valuation and decreases the amount attributable to IT. They also found that market valuation effects are greatest for firms that have high levels of investment in both IT and organizational capital, pointing again to the complementarity of the two factors.

So far, studies have failed to identify a relationship between IT investment and firm profitability. Hitt and Brynjolfsson [1996] showed that while IT investment affects productivity and contributes to consumer welfare (through lower prices or better service, for example), it does not necessarily improve profitability. They proposed that the productivity benefits associated with IT use may be passed on to consumers through lower prices and not lead to greater profitability. On the other hand, in our assessment, it is possible and even likely that IT investments do actually affect profitability, but that the modeling techniques and datasets used in these studies are unable to measure the impacts. As models are developed that are able to control for more of the additional factors that affect profitability, they may reveal a relationship between IT investment and financial performance.

3.5. IT and Labor

Firm-lavel studies have shown that IT capital has been a net substitute for labor, as the use of IT allows firms to reduce headcounts or to grow output faster than employment [Dewan and Min 1997]. In addition, IT use is associated with a shift toward workers with higher skill levels, a process referred to as *skill-biased technical change*, and these workers earn higher wages on average. Comparing industry sectors, Autor et al. [1998] found that the rate of skill upgrading has been most rapid in industries that are the most intensive users of computers. Looking at the U.S. labor force, Krueger [1993] found that workers who used computers earned 10 to 15% more than nonusers. Similar results have been found in studies of other developed countries [Chennells and Van Reenen [1999].[5] Dinardo and Pischke [1997] offered a competing perspective, finding not just a strong correlation between wages and computer use in German data, but equally robust correlations for workers who use pencils, pens, calculators, or telephones. They argued that these findings cast doubt on the interpretation that the wage differential reflects returns to computer use, but reflect, in fact, the nature of the work and the implied skill sets of the

[5] These authors have provided a broad survey of research in this area.

workers. Moreover, as Chennells and Van Reenen [1999] pointed out, there is much evidence that workers with the best skills are given the best technology to use.

It is also important to identify what mechanism might account for the relationship between computer use and skill level. Bresnahan [1999] argued that the process of skill upgrading is due to organizational changes related to computerization rather than to individual use of computers. In particular, computer systems enable work to be shared between a worker and the system, with many standard and repetitive tasks now conducted by the system but many of the higher cognitive tasks still conducted by the worker. Correspondingly, much clerical work is conducted by automated systems today, changing the nature of clerical work to focus on more complex situations and those that require human intervention. In the case of highly educated workers, work is supported rather than automated by computers. In this view, organizational computing systems have been a substitute for low- and middle-skill white collar workers while creating more demand for high-skill workers. This process could explain the higher skill levels and wage rates associated with IT use.

In an empirical study, Bresnahan et al. [2002] tested the relationship between IT use, organizational change, and skill levels at the firm level. They found that the use of IT, along with complementary workplace reorganization and a higher rate of introduction of new products and services, all tend to result in greater use of high-skilled labor. They also found that organizational changes accompanied by technology change may have a greater impact on skill levels than technology change alone. These findings are consistent with the view that IT-enabled organizational changes are responsible for the shift toward higher-skilled workers.

3.6. Summary of Firm-Level Studies

While earlier studies showed mixed results, nearly all major studies since the mid-1990s have shown positive and significant returns to IT investments, and in most cases higher gross returns than for other investments. An important point is that the data utilized in the studies run from the late 1980s to the mid-1990s, before the Internet boom and before the advent of the so-called "New Economy." As such, the research shows that the issue of whether firms benefit from their IT investments can be separated from the question of whether the late 1990s productivity surge at the country level was a temporary development or the beginning of a long-term structural shift in the economy.

While average returns have been high, there is a great deal of variance among firms in returns to IT investments. Complementary management practices such as decentralization of decision-making, business process redesign, and total quality management are found to be critical to the level of returns to IT investment achieved by firms.

Studies also have shown that IT capital can be substituted for other types of capital and labor, and that IT investment is associated with a shift to higher-skilled workers. One explanation is that organizational computing systems have been a substitute for low- and middle-skilled white collar workers while creating more demand for high-skilled workers.

Firm-level studies have so far failed to show a clear link from IT investment to profitability. The failure to document these results most likely has stemmed from the inability to quantify and incorporate the various unobservable factors that determine a firm's competitive position and outcomes.

While firm-level studies show that IT investments have higher gross marginal products than non-IT investments, there are reasons to be skeptical of claims that firms are systematically underinvesting in IT. Once factors such as incomplete accounting of complementary investments, high rates of obsolescence, and risk adjustments are taken into account, the returns to IT investments are likely to look more normal.

Finally, it should be noted that most of the firm-level research has involved data on large firms, as it is more difficult to get good financial data on smaller firms, which are usually privately held. Therefore, the results of firm-level studies cannot be taken to represent the entire universe of firms. It may be that a more representative sample would show either higher or lower returns to IT investment. This is an area ripe for future research if better datasets can be developed on small and mid-sized firms.

4. INDUSTRY-LEVEL RESEARCH

While some of the firm-level studies have focused on a particular industry, or have compared results from different sectors (e.g., services vs. manufacturing), there is a dearth of studies using aggregate data at the industry level. Attempts at such studies have suffered from inconsistencies in U.S. industry-level data as identified in Baily and Gordon [1988] and elsewhere, which are discussed in Section 6. As one might expect from such limited research with serious data problems, there has been considerable divergence in the results. Indeed, as we shall see, some of the most important open questions pertain to the breadth of the IT payoff among industry sectors. That is, do the payoffs from IT investment occur across a large number of industries, or are they confined to a few?

4.1. Average Labor Productivity Growth

A number of recent studies of the productivity revival of the late 1990s have shown that labor productivity growth accelerated in many industry sectors in the 1995–1999 period over earlier periods [Jorgenson and Stiroh 2000; Council of Economic Advisors 2001; Stiroh 2001a, 2001b; Baily and Lawrence 2001; Nordhaus 2001]. One study [Gordon 2000] found that acceleration of labor productivity growth was concentrated in the durable goods manufacturing sector, and most of that in the IT-producing industries. However, Gordon [2001] has since updated his study to include data for 2000 and now finds acceleration in labor productivity outside the durable goods sectors as well.

The research has also shown that there is variation across industries. Studies by the Council of Economic Advisors [2001] have shown that the overall pattern is one of positive and in some cases very substantial change (Table I). The CEA studies have also shown that this positive change in labor productivity is associated with greater IT investment. Those industries that have made greater investments in IT also experienced greater change in labor productivity. For example, as shown at the bottom of Table I from the 2001 CEA study, average productivity growth from 1995–1999 was four times greater (4.18% vs. 1.05%) in industries with intense IT investment than in those with less intense investment. Moreover, the increase in average productivity for the industries with intense IT investment was also greater between the 1989–1995 and 1995–1999 periods than it was for those with less intense investment (Table I).

The CEA findings are reinforced by Stiroh [2001a, 2001b], who compared productivity gains during the 1990s in 61 industry sectors and founds that two-thirds showed a positive shift in labor productivity after 1995. Moreover, he found that IT-intensive industries (those with higher than average levels of IT capital as a share of total capital) showed a 1.3% higher labor productivity acceleration than other industries from the early to late 1990s, and had higher productivity growth in both periods. This provides further evidence that IT use was strongly identified with the acceleration of labor productivity in the late 1990s.

A study by the McKinsey Global Institute [2001] found that 38 industry sectors, accounting for 70% of GDP, experienced productivity increases post-1995. Six sectors accounted for 74% of the total productivity increase, and another 26 sectors accounted for 26%. Thus, a reasonable conclusion from the McKinsey study, which is consistent with the Council of Economic Advisors [2001] and Stiroh [2001a, 2001b] analyses, is that the productivity revival was broad-based as more than half of the industry sectors experienced increased productivity.

Table I. Labor Productivity Growth* by Industry, 1989–1999

Industry	1989–1995	1995–1999	Change
Private industries	.88	2.31	1.43
Agriculture, forestry, fisheries	.34	1.18	0.84
Mining	4.56	4.06	−.50
Construction	−.10	−.89	−.79
Manufacturing	3.18	4.34	1.16
Durable goods	4.34	6.84	2.51
Nondurable goods	1.65	1.07	−.59
Transportation	2.48	1.72	−.76
Trucking and warehousing	2.09	−.78	−2.82
Transportation by air	4.52	4.52	.00
Other transportation	1.51	2.14	.63
Communications	5.07	2.66	−2.41
Electric, gas and sanitary services	2.51	2.42	−.09
Wholesale trade	2.84	7.84	4.99
Retail trade	.68	4.93	4.25
Finance, insurance and real estate	1.70	2.67	.97
Finance	3.18	6.76	3.58
Insurance	−.28	.44	.72
Real estate	1.38	2.87	1.49
Services	−1.12	−.19	.93
Personal services	−1.47	1.09	2.55
Business services	−.16	1.69	1.85
Health services	−2.31	−1.06	1.26
Other services	−.72	−.71	.01
Industries by intensity of IT use			
Intense IT use	2.43	4.18	1.75
Less intense IT use	−.10	1.05	1.15

*Value added per full-time equivalent employee; average annual percent change.
Source: Council of Economic Advisors [2001].

A recent study by Triplett and Bosworth [2002] focused on productivity in 27 industries in the services sector. It is the first study to look at this sector in such detail and identify the impacts of IT and other factors on productivity growth. The study found that, post-1995, the most IT-intensive industries in the U.S. economy are overwhelmingly services industries and that labor productivity growth in the services industries has proceeded at about the economy-wide rate. Moreover, labor productivity growth is broadly based—it is not limited to just a few large services industries. These findings are especially important because they show that the productivity improvement post-1995 was broad, and they dispel the belief that the inherent nature of services makes productivity improvements less likely than in the manufacturing sectors of the economy as a whole. Moreover, they show that IT, through capital deepening, played an important role in labor productivity both pre- and post-1995: "It was often not new IT, or new IT investment, that was associated with rapid productivity change, but instead IT capital technology that had been around for a decade or two" [Triplett and Bosworth 2002, p. 18].

4.2. Multifactor Productivity Growth in IT-Producing Industries

There is considerable agreement among economists that multifactor productivity has increased in the IT-producing industries [Gordon 2000; Jorgenson and Stiroh 2000; Oliner and Sichel 2002; Council of Economic Advisors 2001]. As an example, Jorgenson [2001] attributes two-thirds of the growth in MFP in the 1995–1999 period to the IT-producing sector (Figure 2). Specifically, he attributed

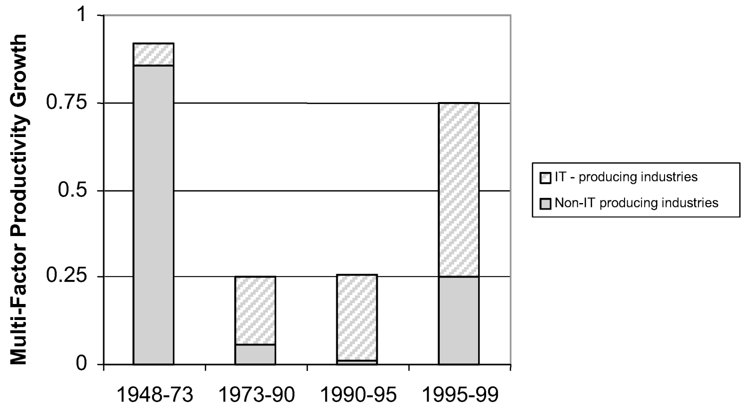

Fig. 2. Contribution of IT-producing industries to MFP. (Source: Based on data from Jorgenson [2001].)

the growth in MFP to continuing technical innovation (R&D) in the semiconductor and computer industries. More rapid price declines occurred from 1994–1999, with the result that computer and telecommunications equipment prices have declined by 90 percent over the period. This increase in productivity in the IT-producing sector has naturally contributed to MFP growth in the whole economy given its increasing share of the national economy.

4.3. Multifactor Productivity Growth in the IT-Using Industries

While there is agreement about MFP growth in the IT-producing industries, there is some debate about whether MFP growth has also increased in the IT-using industries. Most studies have attributed some multifactor productivity growth in the recent 5 years to the IT-using industries as well as the IT-producing industries [Whelan 2000; Jorgenson and Stiroh 2000; Oliner and Sichel 2002; Council of Economic Advisors 2001; Baily and Lawrence 2001]. However, Gordon [2000] found no evidence of MFP acceleration outside of the IT-producing and durable goods manufacturing industries.

This controversy about the contribution of MFP in IT-using industries was a motivation for the recent Triplett and Bosworth [2002] study of the services sector. They found that the sources of labor productivity improvement in the services industries were growth in MFP, IT capital deepening, and increased use of outsourcing.[6] However, they concluded that MFP was the dominant factor contributing to the productivity acceleration in the services industries post-1995, contributing well over half of the acceleration.

4.4. Summary of Industry Studies

The overall pattern of industry-level studies consistently has shown positive returns in the form of labor productivity increases from IT investments. They also have shown that labor productivity has increased more in industries that use IT more intensively. Most studies showed that productivity increases in the manufacturing industries were higher than those in services. However, a recent study has shown that most services industries have experienced productivity increases comparable to those in manufacturing, and that these increases have been present throughout the 1990s. Thus, the pattern of productivity increases is broad, encompassing many industries in both the manufacturing and services sectors.

There is agreement that MFP growth has increased in the IT-producing sector

[6] Labor productivity improvement from outsourcing occurs because of the use of more specialized, and hence more productive, producers.

due to technical innovation in the semiconductor and computer industries, but there has been some disagreement about whether MFP growth has also increased in the IT-using sector. The most recent evidence suggests that MFP growth has increased in the IT-using industries, and, most significantly, that MFP has increased in the services industries, which have historically posed difficult measurement problems.

5. COUNTRY-LEVEL RESEARCH

As discussed earlier, economists mainly use growth accounting to estimate the contribution of inputs to productivity and output. As discussed in prior sections, economic growth can result from a greater level of inputs (labor and capital), improved quality of the inputs, and greater overall efficiency in the combination of inputs in production. The efficiency with which these factors of production are combined can increase as a result of improvements in production methods, such as managerial practices, organizational changes, and innovative ways of producing goods and services.

The research shows that all these factors explain some of the trends in national economic growth. The key question in our review is the specific contribution of IT capital to this growth, both in terms of labor productivity increases via capital deepening and from multifactor productivity growth.[7]

5.1. Average Labor Productivity Growth

The first studies conducted at the country level in the late 1980s and early 1990s concluded that the contribution of IT to productivity and economic growth was nonexistent or slight [Roach 1987, 1989, 1991; Oliner and Sichel 1994; Jorgenson and Stiroh 1995]. One explanation advanced for this conclusion was that IT investment was too small a portion of the capital stock in the economy to have substantial economic effects [Sichel 1997]. For example, IT capital as a share of total capital investment in nominal dollars in the U.S. was 3.5% in 1980 and 9% in 1990. During the 1990s, IT capital investment increased dramatically, reaching 22% of total U.S. capital investment. One major factor in this increased rate of adoption of IT was an acceleration of the decline in computer prices from an average of 17% annually from 1959–1995 to roughly 32% for the period 1995–1999 [Jorgenson 2001]. Clearly, the decreasing prices of IT have resulted in a significant increase in its demand, encouraging organizations to substitute IT for labor and for other forms of capital such as plant, machinery, or equipment.

With this increased investment, recent studies have found that IT investments have had a major impact on labor productivity and economic growth at the country level. U.S. labor productivity, which grew at 1.5% per year in the 1973–1995 period, grew at the rate of 3.1% per year in 1995–2000. Similarly, gross domestic product (GDP) grew at 3% per year in the earlier period and accelerated to 4.8% per year during the later period [Council of Economic Advisors 2001]. This acceleration in recent productivity and GDP growth has been attributed in significant part by several macroeconomic studies to the impact of IT investment [e.g., Oliner and Sichel 2000; Jorgenson 2001; Jorgenson and Stiroh 2000; Council of Economic Advisors 2001], some of which were authored by researchers who had previously expressed a contrary opinion. Thus, there is considerable agreement that IT investments have had a major impact on labor productivity and economic growth at the country level.

Although much of the current focus is on the IT-led productivity surge of the late 1990s, it is important to point out that these contributions are not new. Recent studies have argued that there

[7] While there is an important conceptual distinction between the sources of productivity growth, the distinction between the sources of growth in labor productivity in empirical analyses is often a rough and ready practical one, as measurement issues and data strengths and weaknesses limit the researcher. It should be pointed out that it is therefore difficult to precisely interpret the allocation of productivity improvements to capital deepening and to MFP in terms of the qualitative impacts of IT systems.

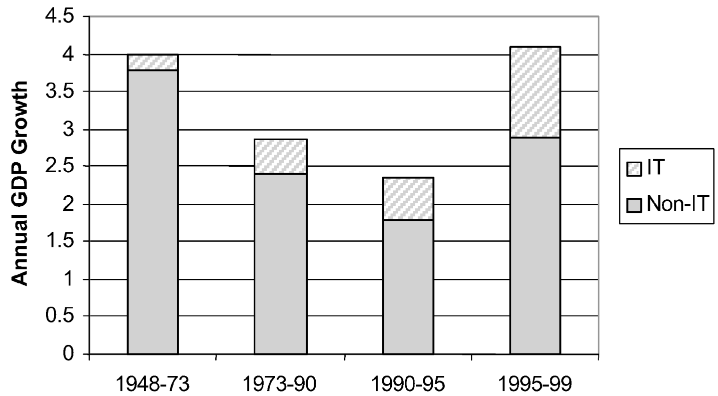

Fig. 3. Contribution of IT and non-IT capital investment to GDP growth. (Source: Based on data from Jorgenson [2001].)

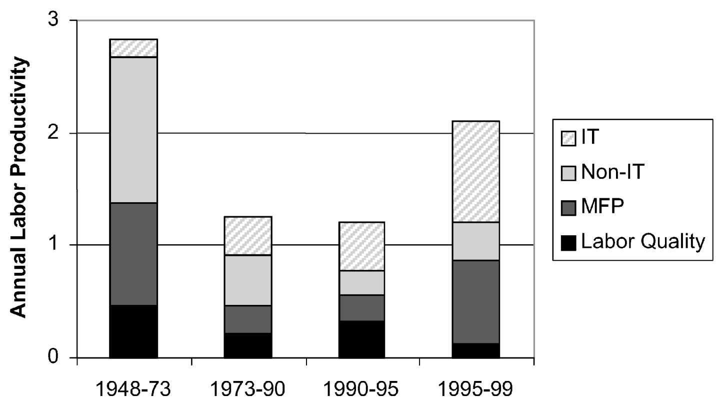

Fig. 4. Contribution of IT and non-IT capital investment to labor productivity growth. (Source: Based on data from Jorgenson [2001].)

have been significant and positive impacts from IT investments for countries for decades [Jorgenson 2001; Oliner and Sichel 2000; Bosworth and Triplett 2000]. While the impacts of IT capital investment were lower because of its lower share of capital stock, IT investment has contributed to U.S. economic and productivity growth for decades, even when the growth rate in labor productivity was low (Figures 3 and 4). While there continues to be a debate over the magnitude of the IT contribution to productivity, there is convincing evidence of significant and positive long-term impacts from IT investments on national productivity.

Early studies by Jorgenson and Stiroh [1995] reported a modest contribution of IT to productivity growth—about 6% of yearly productivity growth of 2.94% (Table II) for the period 1959–1973. In subsequent periods, these researchers found the contribution of IT to be considerably greater. For example, during the period 1973–1995, Jorgenson and Stiroh [2000] found that IT contributed about 13% of the 3.04% economic growth and 27% of the 1.4% labor productivity growth in the U.S. Oliner and Sichel [2000] found slightly higher contributions (Table II).

The acceleration of labor productivity growth from 1995–1999 was due in part to rapid growth in IT investment. The major reason for the increased impact on productivity was simply that investment in IT was increasing at a faster

Table II. Contributions of IT to GDP and Productivity Growth

Jorgenson and Stiroh [2000]; Jorgenson [2001]	1959–1973	1973–1995	1995–1999
GDP growth (annual rate)	4.32	3.04	4.08
Capital contribution (percent of total)	33	50	71
IT contribution to GDP growth (percent of total)	4	13	28
Productivity growth (annual rate)	2.94	1.40	2.11
IT contribution to productivity growth (percent)	6	27	42
Oliner and Sichel [2000]		1973–1995	1995–1999
GDP growth (annual rate)		2.99	4.82
Capital contribution (percent of total)		42	38
IT contribution to GDP growth (percent of total)		17	23
Productivity growth (annual rate)		1.52	2.67
IT contribution to productivity growth (percent)		31	41

Sources: Original studies, plus calculations by Bosworth and Triplett [2000] and the authors. These studies were selected for special focus because they are comparable in that they include similar time periods, the same methodology, and the same definition of IT to include computer hardware and software and telecommunications equipment.

rate and the accumulated investment in IT represented a substantially greater share of the total capital stock than in prior periods.[8] Thus, IT capital contributed more then to the growth of the economy than it did in earlier periods. Jorgenson [2001] showed that during the period 1995–1999, IT capital contributed about 28% of the 4.08%, yearly economic growth and about 42% of the 2.11 percent growth in labor productivity in the United States. Oliner and Sichel [2000] estimated very similar contributions (Table II).

There has been some debate in the recent literature about the share of these improvements attributable to structural changes resulting from technical progress, or changes in the trend line, versus those that are due to the effects of the business cycle. Short-run growth can raise both measured productivity and investment; short-run decline can reduce both. It is difficult to say with reasonable certainty what the precise shares of impacts due to trend and cycle are,[9] though it is clear that both matter. Gordon [2000] attributed a significant share of the 1995–2000 productivity growth acceleration to business cycle effects, while other studies [Council of Economic Advisors 2001; Stiroh 2001] have shown little or no cyclical effects. These different results have substantially different implications for the magnitude of the impact of IT investment on productivity.

Regardless, the importance of these findings is that the broad and continuing use of IT has made a significant difference in long-term labor productivity growth. The Internet and electronic commerce might contribute additionally. A study by Litan and Rivlin [2001] estimated the likely productivity impact from the Internet across eight industry sectors, which account for about 70 percent of the nation's GDP. While admittedly speculative, the study estimates that the impact of the Internet over 5 years could translate into an annual contribution of 0.2 to 0.4% to the baseline trend of productivity growth.

[8] The nominal share of IT investment as a percent of total business investment grew from 2.6% in 1970 to 3.5% in 1980 to 9% in 1990 and 22% in 1999. One major factor in this increased rate of adoption of IT was an acceleration of the decline in computer prices, from an average rate of 17% annually from 1959–1995, to roughly 32% annually for the period 1995–1999 [Jorgenson 2001]. Clearly, the decreasing prices of IT have resulted in a significant increase in demand for it, encouraging organizations to substitute IT for labor and for other forms of capital such as plant, machinery, or equipment. Although IT capital is not a very large portion of total capital investment, there is no evidence that IT investment has reached a point of diminishing returns.

[9] There are considerable measurement issues related to output. While aggregate statistics are widely believed to capture business cycle effects, they are likely to underestimate quality improvements in outputs, and particularly those that are enabled by IT use.

5.2. Average Labor Productivity Growth in Other Developed Countries

While there has not been as much research comparable to that on the United States elsewhere in the world, most of the foregoing trends have also been found in other developed countries of Europe and Asia. For example, Schreyer [1999] looked at G-7 countries and found that IT made a positive contribution to productivity and economic growth in all of the countries during the period 1990–1996. Another Organisation for Economic Co-operation and Development (OECD) study [Daveri 2000] updated and extended the analysis to 18 countries. While there were differences between the two studies, the essential findings were the same—IT capital has contributed to growth, and because IT has been growing faster than labor input, it contributes to labor productivity through capital deepening.

These findings have been corroborated by several larger and more robust studies. Two contemporary studies of 36 (plus) countries worldwide came to the interesting conclusion that wealthier, industrialized countries showed a positive and significant relationship between IT, growth and productivity, but that there was no evidence of such a relationship for developing countries [Dewan and Kraemer 1998, 2000; Pohjola 2001]. Dewan and Kraemer hypothesized that this gap was due to the low levels of IT investment relative to GDP in developing countries, and to the lack of complementary assets such as the necessary infrastructure and knowledge-base to support effective use of IT. Kraemer and Dedrick [2001] studied a sample of 43 developed and developing countries and found that growth in IT investment per worker was positively correlated with labor productivity growth, but the level of IT investment was not.

5.3. Summary of Country Studies

The large price/performance changes in IT equipment have stimulated increases in IT capital investment in the U.S. and other countries in the expectation of improved economic performance. The surge in IT investment during the mid- to late-1990s led to a sharp acceleration in labor productivity growth, but it is important to recognize that IT investments have been paying off in terms of labor productivity for over 30 years. As IT has become a larger share of total capital investment by firms, so has its contribution to labor productivity and to economic growth.

6. EVALUATION OF THE STATE OF RESEARCH

A careful assessment of the literature brings to the forefront a range of underlying research issues that makes it difficult to precisely estimate the returns to IT investment.

6.1. Measurement Problems

Accurate estimation of the returns to IT investment requires accurate measurement of the inputs and outputs in the production processes of firms and industries. Measurement issues are quite daunting in this field. In particular, measuring outputs in the services sector, which owns the majority of IT capital, is very difficult, as is accounting for changes in the intangible attributes of products such as quality and variety in the manufacturing sector [Bosworth and Triplett 2000]. Accurate measurement of firm outputs requires data on quality-adjusted prices for these outputs, which is usually unavailable.

On the input side, it has been quite challenging to develop quality-adjusted price indexes for IT inputs. In the case of hardware, government agencies like the Bureau of Economic Analysis, in concert with academic and computer industry economists, have made significant strides in developing quality-adjusted price indexes for computer equipment [Cole et al. 1986; Dulberger 1989]. On the other hand, it has proven to be very difficult to account for investments in software. It is not only conceptually challenging to define units of software; it is also difficult in practice to account for the large investments that firms have made in custom software. While there has been considerable progress in developing price indexes for packaged software, the same is not true for custom software. Indeed, it was only in 1999 that software was reclassified as an investment rather than an expense in the national accounts.

6.2. Statistical Issues

There are estimation issues as well; a few key concerns are discussed here. In production function approaches, perhaps the most significant of these is the notion of simultaneity in investment and growth due to unobservable factors. For example, a firm with attractive growth options may choose to invest in increasing amounts of IT to enable its growth. Statistical techniques may find evidence of a correlation between IT investment and growth, but not recognize that these are simultaneously determined by an unobservable factor—for example, a firm's growth options—and erroneously attribute this growth to IT investment. Virtually all studies employ advanced techniques to address this concern; what is uncertain is how successful these techniques are in distinguishing between these two effects.

These same problems arise with macroeconomic data: Is an increase in investment a cause of an increase in GDP, or vice versa? Aggregate labor productivity tends to increase when the labor market is tight since firms try to squeeze more output from their existing workers. The very low rates of unemployment in the later 1990s would naturally lead to an increase in measured productivity. Researchers have attempted to adjust for these business cycle effects, but it is still debatable how well they have succeeded.

In spite of legitimate concerns about measurement, data, and statistical models, the evidence of positive and significant productivity gains related to IT investment is still strong. The issues raised point to difficulties in arriving at precise estimates of returns on investment, and of sorting out the relative contributions of labor productivity versus MFP. The fact that a large number of studies using different datasets and different models come to similar conclusions makes for strong evidence of payoffs to IT investments relative to capital deepening. On the other hand, better measurement of output quality could lead to better estimates of the return to IT investment. Accordingly, one promising avenue for further research is the development of better measures of investment in capital and labor, and of methods of accounting for previously uncounted investments.

7. OPPORTUNITIES FOR FUTURE RESEARCH

7.1. Sources of Productivity Growth

The research evaluated in this review highlights a set of fundamental issues and questions that are critical to developing an understanding of the mechanisms by which IT pays off in higher productivity. In particular, IT can impact labor productivity via capital deepening, and in MFP growth through improvements in production methods. The first finding is consistent with a traditional neoclassical economics view which also implies that firms receive diminishing returns from continuing investment in IT as opportunities for investment decline with increasing levels of IT stock. In this view, technical progress originates exogenously in the computer industry, and ongoing investment by firms in the outputs of the IT industry drives productivity growth. On the other hand, a payoff in labor productivity via capital deepening plus MFP growth may be indicative of constant or increasing returns. Such a finding requires the identification of a mechanism by which capital might not experience decreasing returns.[10] In particular, one explanation for this structure of returns is the possibility of spillovers in which firms benefit not just from a private investment in an asset but also from a growth in the

[10] This notion is central to new growth theory, which focuses on endogenous growth and constant or increasing returns; c.f. Romer [1986].

asset stock of all firms. The McKinsey Global Institute [2001] provided a telling example of this phenomenon in the retail sector, where Wal-Mart's productivity gains from innovations in IT and associated management practices have spurred competitors to make similar investments leading to productivity improvements in the industry broadly.

7.2. Spillover Effects

An understanding of whether these spillovers exist and how they occur is central to developing a comprehensive framework for understanding the returns to IT investment and for developing guidelines for the successful deployment of these technologies. A critical feature of this debate is whether IT is like traditional forms of capital, such as tangible assets and human capital, or whether it is more like knowledge capital, which is significantly different. In the case of traditional capital investment, returns accrue primarily to the firm making the investment and receive diminishing returns from continuing investment. On the other hand, some economists hold that knowledge capital can be owned and used by many parties simultaneously, leading to potential spillovers, and that the returns may be difficult for a single firm to capture in the presence of spillovers to other firms. These spillovers can lead to endogenous technical progress.

Clearly, IT capital has aspects of both forms of capital. As a production technology, it is similar to traditional forms of capital. In its informational and transformational roles, it is similar to knowledge capital. Best practice information regarding the management of technology, complementary organizational practices, and techniques for better information use does lend itself to use by many firms. Such knowledge is often diffused by entities such as technology user groups, academic institutions, management consulting firms, and, especially, labor mobility. It is often the case that competing firms rapidly copy IT investments made by innovative firms.

7.3. IT and Firm Financial Performance

Firm-level studies have failed to identify a relationship between IT investment and firm profitability. Hitt and Brynjolfsson [1996] showed that while IT investment affects productivity and contributes to consumer welfare (through lower prices or better service, for example), it does not necessarily improve profitability. They proposed that the productivity benefits associated with IT use may be passed on to consumers through lower prices and not lead to greater profitability. On the other hand, it is possible and even likely that IT investments do actually affect profitability, but the modeling techniques and datasets used in these studies are unable to measure the impacts. It is important, therefore, to develop better datasets and also to develop models that are able to control for more of the additional factors that affect profitability, with the possibility of revealing a relationship between IT investment and financial performance. It is also important to measure the impacts of IT on intermediate outputs such as inventory levels, planning cycles, asset utilization, and other measures of operations performance, which are known to have a direct link with profitability.

7.4. Excess Returns at the Firm Level

Another issue that deserves further attention is the high returns to IT use that some firms appear to have accrued. Some evidence suggests that firms in durable goods industries have achieved substantially larger returns than firms in nondurable goods industries, while other evidence suggests that the returns to IT investment are broader and accrue to a wider range of firms if lagged payoffs are taken into account. As pointed out here, IT must have a high gross return to allow for rapid depreciation and obsolescence, and it is also the case that investments in complementary assets such as software, training, and organizational transformations have been undercounted. It is important to develop an understanding of the mechanisms by which these returns accrue to firms. Studies should also attempt to include adjustments for the risk involved with IT investments.

7.5. Timing of Payoff from IT Investments

A better understanding of the timing of the payoff from investments in IT capital is also needed. Clearly, a firm's many individual investments in specific systems will have different periods over which the payoffs will be realized. Some systems will realize immediate payoffs, while others will realize payoffs after a lag. The duration over which the payoffs will be realized will also vary. Some will have short-term impacts and others will have longer-term impacts. This understanding will go a long way toward resolving the debate over whether the impact of these investments is contemporaneous or occurs in the future.

7.6. Industry Differences

It is not well understood why firms in different industries accrue different payoffs. At aggregate levels, an explanation that is generally consistent with the traditional, neoclassical approach has been advanced. That is, in computer-using industries, the mechanism through which IT provides a payoff is increasing labor productivity via capital deepening; in the computer-producing sector, and the durable goods sector, more generally, the mechanism is primarily technical progress, measured as growth in MFP. While the evidence for this is compelling overall, there are some important unanswered questions. For one, it is unclear why some IT-intensive industries—such as consumer banking and insurance—have not seen gains until recently in labor productivity in spite of long-term, large investments in IT. While the difficulty in measuring outputs in these industries is one of the likely explanations, more research is required to fully understand this result. It is also somewhat unclear why durable goods manufacturing achieves significant MFP gains while nondurable manufacturing does not. Finally, it is not understood why technical progress has accelerated in recent years in the computer-producing sectors of the economy, although some have argued that intensified competition in the semiconductor industry in the late 1990s led to faster product cycles.

8. CONCLUSION

As the foregoing review shows, IT and economic performance has become a key area of research in the information systems field with contributions being made by information systems researchers, management scientists, and economists. The area has grown from less than a dozen studies in the 1980s to more than 50 studies in the 1990s. The research on IT payoffs is complex, employing a number of analytical tools to study a variety of firms, industries, and countries. Different studies sometimes come to conflicting conclusions, and researchers have different interpretations of what the data mean. What is particularly significant about these studies is that whereas the early studies were inconclusive, studies that are more recent have shown considerable convergence. Beyond all the complexity of the field, three fundamental conclusions clearly emerge from this review.

First, the productivity paradox as originally stated by Robert Solow [1987], which was always more of a straw man than an economic analysis, has been put to rest. A number of major studies have documented the significant impact of IT investment on the productivity of firms, industries, and countries, showing that computers do, in fact, show up in the productivity statistics.

Second, while the so-called "New Economy" and the high IT returns captured the media's attention in the late 1990s, IT investments actually have been increasing productivity for more than three decades.

Third, and most significantly for firms, although returns to IT investments are positive on average, there is a wide range of performance among different companies, with some doing much better than others. Some of these differences can be explained by idiosyncratic firm differences that result in different opportunities to employ IT productively. In addition, there is strong evidence that investments in organizational capital through management practices such as decentralized decision-making, job training, and business process restructuring have a major impact on returns to IT investments. The value of IT investments needs to be seen in relationship to investments in such organizational capital, as the two are complementary. IT is not simply a tool for automating existing processes, but is more importantly an enabler of organizational changes that can lead to productivity gains.

While Solow's paradox has been resolved, this review and evaluation of the literature indicates that the issue of returns to IT investments is far more complex than the original formulation, and hence more research is needed. The evaluation highlighted a range of underlying issues that need to be addressed in ongoing and future research. Chief among these are measurement issues regarding the inputs and outputs of firms and industries. Improved measurement of inputs, especially of software and intangible assets, such as R&D and human capital, is a first step. A much more important but difficult step is improved measurements of outputs. This is particularly critical for the services sector, where measurement problems are the most severe. IT returns are least understood and possibly underestimated in this sector that accounts for two-thirds of the U.S. economy.

This review has also identified priority areas for future research. Three are particularly important for professional practice. The first is further analysis of the mechanisms by which some firms receive high returns from IT use, and in particular, the returns from investments in complementary assets. The second priority is explaining why some IT-intensive industries have not seen gains in labor productivity in spite of large investments in IT. In addition to being of practical importance, these two priority areas will help to address some of the difficult theoretical and measurement issues in the field. The third is solving the profitability paradox, or the general failure of studies to show a positive relationship between IT investment and measures of overall financial performance. It is important to develop better datasets and also to develop models that are able to control for more of the additional factors that affect profitability.

Finally, the results of this review must be put into perspective given recent events in the economy. In mid-2000, IT capital investment began to fall sharply, partly due to higher interest rates and slowing economic growth. Moreover, the collapse of many Internet firms had far-reaching impacts. Not only did their own investments in IT disappear, but their collapse also reduced the competitive pressure on established firms to invest in IT to respond to these newcomers. This reduction in IT investment has had devastating effects on the IT-producing sector, and may lead to slower economic and productivity growth in the U.S. economy. Nevertheless, IT investments are expected to continue to contribute to productivity [Jorgenson et al. 2002; Oliner and Sichel 2002]. In a recent critical review, Joseph Stiglitz[11] characterized the U.S. economy and the role of IT as follows:

> In many ways, the fundamentals of the U.S. economy are strong, and they were strengthened during the 1990s. The New Economy is real, even if its significance has been exaggerated. New technology has engendered increases in productivity that will continue to make an enormous difference in our living standards. [Stiglitz 2002, p. 88].

While the turmoil in the technology sector has been unsettling to investors and executives alike, it should not overshadow the fundamental changes that have occurred as a result of firms' investments in IT. These companies are engaging in complementary management practices that enhance the returns to IT investment, discovering and exploiting the efficiencies that the Internet and other networks enable, and achieving significant gains in productivity.

[11] Joseph Stiglitz was chairman of President Clinton's Council of Economic Advisers, chief economist of the World Bank, and winner of the 2001 Nobel Prize in Economics.

APPENDIX: SUMMARY OF STUDIES ON IT RETURNS

Table A1. Selected Firm-Level Studies of IT Returns

Study	Data sample	Findings
	IT and firm performance	
Strassmann [1990]	38 U.S. companies	No correlation between IT spending and firm performance.
Loveman [1994]	60 Business units in 20 U.S. companies	IT investments add nothing to output.
Barua et al. [1995]	Same as Loveman [1994]	IT improves intermediate output if not final output.
Brynjolfsson and Hitt [1993]	Large U.S. manufacturers	Gross marginal product of IT is over 50 percent per year in manufacturing.
Brynjolfsson and Hitt [1995]	Large U.S. manufacturers	Firm effects account for half of productivity benefits of earlier study.
Lichtenberg [1995]	U.S. firms, 1989–1991	IT has excess return; one IS employee can be substituted for six non-IS employees without affecting output.
Brynjolfsson and Hitt [1996]	367 Large U.S. firms	Gross return on IT investments of 81 percent. Net return ranges from 48–67 percent depending on depreciation rate.
Hitt and Brynjolfsson [1996]	370 U.S. firms	IT investments increase firm productivity and consumer welfare, but not profitability.
Dewan and Min [1997]	300 Large U.S. firms	IT is a net substitute for both capital and labor, and shows excess returns relative to labor input.
Black and Lynch [1997]	1621 U.S. manufacturing establishments	Productivity not affected by presence of a particular management practice, but by implementation, especially degree of employee involvement. Non-managerial use of computers related to productivity.
Brynjolfsson et al. [1998]	Sample of *Fortune* 1000 U.S. firms, 1987–1994	The stock market value of $1 of IT capital is the same as $5–20 of other capital stock.
Gilchrist et al. [2001]	Sample of *Fortune* 1000 U.S. firms	IT productivity is greater in IT producer firms than in user firms and in durable manufacturing.
Greenan et al. [2001]	French firms	Gross returns to IT investment are positive and greater than returns to non-IT investment.
	Organizational complements and IT returns	
Bresnahan et al. [2002]	400 Large U.S. firms, 1987–1994	The effects of IT on labor demand are greater when IT is combined with particular organizational investments.
Brynjolfsson et al. [1998]	Sample of U.S. firms, 1996	Decentralized organizational practices, in combination with IT investments, have a disproportionate positive effect on firm market value.
Ramirez et al. [2001]	200+ U.S. firms, 1998	Firm use of employee involvement and total quality management enhances IT returns.
Francalanci and Galal [1998]	52 U.S. life insurance companies, 1986–1995	Productivity gains result from worker composition (more information workers) and IT investments.
Devaraj and Kohli [2002]	8 Hospitals, over 3 years	IT investment combined with business process Reengineering positively and significantly influences performance.
Tallon et al. [2000]	300+ U.S. firms, 1998	Perceived business value of IT is greater when IT is more highly aligned with business strategy.

Table A2. Selected Country and Industry-Level Studies of IT Returns

Study and date	Sample	Key findings
U.S. studies		
Oliner and Sichel [2000], Jorgenson and Stiroh [2000]	1973–1999	IT investment contributed one-half of GDP and labor productivity growth between 1995–1999 and contributed moderately during earlier periods. IT contributes to productivity in the T-using *and* -producing sector.
Stiroh [2001a; 2001b]	61 Industries, 1987–1999	IT-using industries show productivity acceleration during 1995–1999. IT-intensive industries show larger productivity gains than non-IT intensive ones.
Council of Economic Advisors [2001]	1973–1999	IT investment contributed about one-half of the acceleration in productivity growth of 1995–1999 over 1973–1975. IT-intensive industries in non-goods-producing industries show MFP gains.
Robert Gordon [1999, 2000]	1972–1999	IT investment contributes positively to MFP growth, but all in the IT-producing and other durable industries rather than in the IT-using industries.
Jorgenson [2001]	1948–1999	IT investment contributed more than one-half of the 1 percent increase in economic growth since 1995. About one-half the productivity growth since 1995 has occurred in the IT-producing sector but growth has occurred in IT-using industries as well.
Nordhaus [2001]	16 Industries, 1978–1998	Labor productivity acceleration in 1995–1998 is not narrowly focused on a few new economy sectors.
Jorgenson and Stiroh [1995]	1958–1992, 1985–1992	IT investment associated with 0.5 percent incremental economic growth.
Oliner and Sichel [1994]	1970–1992	IT investment too small to have substantial economic IT associated with 0.16–0.28 percent additional effects; economic growth.
Roach [1987, 1989, 1991]	1970–1987	Large increase in IT investment per worker in services sector appears along with decrease in measured output per worker.
Other country and cross-country studies		
Schreyer [1999]	G-7 countries, 1990–1996	IT contributes significantly to productivity growth in all seven countries, but the magnitude differs across countries.
Daveri [2000]	18 OECD and European Union (EU) countries, 1992–1997	IT added to GDP growth in the 1990s for all countries studied, but the contribution in EU countries was smaller than in other industrialized countries. Within the European Union, differences in IT contribution to growth were also due to lower IT investment.
Pohjola [2001]	39 Countries, 1980–1995	IT investment shows 80 percent gross returns for OECD countries; nothing significant for developing countries.
Kraemer and Dedrick [1994]	12 Asia-Pacific countries, 1984–1990	IT investment positively correlated with GDP and productivity growth.
Dewan and Kraemer [1998, 2000]	36 Countries, 1987–1993	IT positively correlated with labor productivity in developed countries, but not in developing countries.
Kraemer and Dedrick [2001]	43 Countries, 1985–1995	Growth in IT investment correlated with productivity growth. Level of IT investment (percent of GDP) not correlated with productivity growth.

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