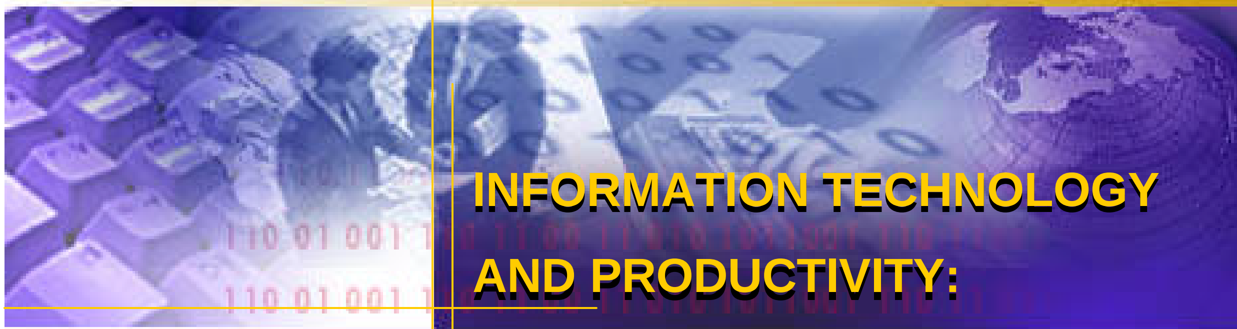

INFORMATION TECHNOLOGY AND PRODUCTIVITY: RESULTS AND POLICY IMPLICATIONS OF CROSS-COUNTRY STUDIES

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ABSTRACT

Technology has long been held to contribute to economic growth through productivity improvement, but early studies of information technology (IT) investments and economic growth found no significant relationship. Indeed, despite large IT investments, national productivity growth in the United States declined in the 1970s and 1980s, leading some to call the situation a productivity paradox. The most persuasive theoretical explanation for the paradox is that IT investments generally have been too small a percentage of the inputs to the economy to have measurable effect.

By the mid-nineties, however, IT investments had grown to 4-5% of GDP in the U.S. and many developed countries. Recent empirical studies at the company and country levels have shown that information technology is positively related to corporate and national economic performance. Analysis of data from 43 countries over 11 years presented in this paper, as well as other recent analyses, show a positive and significant relationship between growth in IT investments and growth in both GDP and labor productivity, even when controlling for growth in non-IT investments. While none of the studies support the hypothesis that IT investment might dramatically speed up development, they clearly show that persistent, growing IT investment does pay off for countries.

The fact that investment in IT use can lead to economic payoffs has policy implications for countries seeking to realize those payoffs. Many countries have focused on promoting IT production rather than IT use. However, this analysis argues that there are gains to the whole economy from investment in IT use as opposed to only a single industry sector from IT production. Moreover, there are sectors of the IT industry that are closely linked to local IT use, specifically the information services industry. These activities, referred to as "production close

to use," not only help countries achieve effective use of IT, but they also offer significant opportunities for developing local IT industries.

Policies that emphasize IT use and production close to use are likely to benefit developing countries that otherwise might be left behind in the emerging information age. To realize these benefits, countries need to develop national capabilities, in the form of human resources and information infrastructure. An appropriate mix of short-term and long-term policies is needed to create a national environment in which payoffs from IT investments can be achieved.

INFORMATION TECHNOLOGY AND ECONOMIC DEVELOPMENT: RESULTS AND POLICY IMPLICATIONS OF CROSS-COUNTRY STUDIES

INTRODUCTION

Information technology has become an omnipresent part of life in industrialized countries, from PCs in offices to microcontrollers in cars and VCRs, from Silicon Valley to Wall Street, where fortunes are made from faster chips and better software. Yet there remains a nagging doubt as to the true value that is being realized from the rapid technological progress and soaring investments in IT. Dubbed the “productivity paradox,” the recurring question is why IT seems to show up “everywhere but in the economic statistics.” In other words, after spending trillions of dollars on IT, why have the U.S. and other developed countries remained mired in relatively low productivity growth for the past two decades?

The question of the value of IT is in some ways even more troubling for developing countries. If it turns out that IT is truly at the heart of the next great wave of innovation and economic growth, developing countries risk being left out due to their relatively low levels of IT investment, poor IT skills, and lack of infrastructure to support IT use. On the other hand, if those countries try to develop those capabilities, they could be wasting very limited resources if it turns out that IT-led productivity is a chimera.

Understandably, there is a great deal of debate among leaders in developing countries as well as in the international development community about the potential for IT in improving productivity and spurring economic development. Countries such as Singapore, Taiwan, Israel, and Ireland have promoted production and/or use of computers as part of a national economic strategy, with notable results. Other countries at earlier stages of development, such as Malaysia and Thailand have begun to implement national IT plans in hopes of achieving similar success. Countries such as Brazil, Mexico, Turkey, the Philippines and Vietnam have developed IT policies, but have only limited resources to put behind their plans. In many developing countries, there is debate over whether resources should be diverted from other needs to invest in IT.

Among development agencies such as the International Monetary Fund and the World Bank, there is likewise disagreement as to what role IT should play in various development projects. Some believe that there are strong payoffs from IT projects while others are skeptical (Rahim and Pennings, 1987; APO, 1990; Mody and Dahlman, 1992). Similar concerns can no doubt be found throughout the development community.

In order to inform the discussion and help guide national and international policies, there is a great need for robust evidence as to the value of IT investment. At one level, there is the question as to whether IT pays off at all, even in developed countries. After all the productivity paradox was coined first in reference to the U.S. economy. The second question is this: Even if IT is a good investment for developed countries, which have well-developed physical infrastructures and educated workers, is it a good investment for developing countries, or should they concentrate on more basic needs first? Finally, if IT investment does have the potential for promoting economic development, what factors determine whether or not those benefits will actually be realized in a given country or region?

These are complex issues, and require a combination of detailed data analysis as well as qualitative analysis of the process of economic growth and development and what role IT can play in that process. This paper reviews findings from past studies of returns on investment in IT, and introduces findings from a new study that is the most comprehensive cross-country data analysis undertaken so far. The analysis is framed in a conceptual framework that draws both on recent theories of economic growth and historical studies of innovation and development.

ECONOMIC GROWTH AND DEVELOPMENT

Technology and Economic Growth

There is a growing consensus among economic growth theorists and development specialists that technology innovation and diffusion can play a critical role in stimulating economic growth and productivity. Early proponents of this view included Van Gelderen (1913), Schumpeter (1939), Abramovitz (1956), Kendrick (1956) and Solow (1957). More recently, economists such as Arthur (1994) and Romer (1990) have emphasized technological innovation in explaining economic growth and productivity gains. Romer in particular argues that economic growth and technological change are inextricably linked. First, increased levels of capital and labor by themselves can lead to economic growth, but without innovation, the returns to incremental increases in capital and labor will diminish, and productivity gains will be be limited or non-existent. Second, as technological innovation is codified into instructions such as software code or semiconductor designs, the diffusion of those instructions can result in increasing returns to scale, as the average cost of such as set of instructions declines with each new user. Thus, widespread technology diffusion creates the possibility for increasing returns to investment (Arthur, 1996).

IT and Economic Growth: Does IT Pay Off?

We would expect to find significant productivity gains in economies with high levels of IT investment because IT has the characteristics described by Arthur (1996) as increasing returns goods. IT products have high up-front development costs and low marginal production costs. IT innovations are largely captured in easily replicated sets of instructions such as semiconductors and software code. Also, they benefit from network externalities. This means that as more people adopt a particular technology such as the IBM/Wintel PC architecture, the value to each user increases as more complementary assets become available (e.g. application software and peripherals) and as it is possible to communicate and share information with other users.

Notwithstanding these facts, there has been a lively debate since the mid-1980s as to whether investments in IT do actually pay off in increased productivity. Some researchers have made a case for IT-led development based on the notion that investments in IT can accelerate economic growth by enhancing worker productivity and increasing the returns to investment in other capital goods (APO 1990; Mody and Dahlman, 1992; OECD, 1988, 1993). In addition, the IT industry itself can be a source of economic growth and jobs. For these reasons, investment in IT is believed to enhance national productivity and competitiveness, spurring economic growth.

The Productivity Paradox

Such a conclusion was disputed by empirical research (Baily, 1986; Baily and Gordon, 1988; Loveman, 1988; Roach, 1987 and 1988; Strassman, 1997) showing that productivity gains from IT in the aggregate economy have been limited, despite the rapid improvement in price-performance ratio of computers and heavy investment in IT. This argument was based in part on the fact that the United States invested heavily in IT during the 1970s and 1980s, yet productivity growth slowed during that period compared to the earlier post-war years. Analysts such as Roach and Strassman have simply juxtaposed the slowdown in productivity growth against the dramatic increases in IT spending over the same period and argued that IT has not resulted in the expected productivity improvements (Figure 1). This pattern of declining productivity growth extends to other developed countries as well.

[Insert Figure 1 here]

The productivity paradox does not mean that IT is necessarily unproductive. On the contrary, those authors who have written most about the paradox tend to stress the enormous *potential* gains. But, Roach (1991), Strassman and others also point out that the effective use of IT is often hampered by many social and organizational barriers.

Recent Firm Level Research

In recent years, several studies have begun to find evidence of significant payoffs from IT investment at the firm level of analysis using different samples of Fortune 1000 companies. Studies by Brynjolfsson and Hitt (1996), Dewan and Min (1997), and Lehr and Lichtenberg (1997) in corporations, and by Lichtenberg (1995) in government agencies as well as corporations, show a high return on IT investment with the estimates ranging from gross rates of return of 50% to over 100%.[1] Moreover, Brynjolfsson and Hitt argue that IT investments have much greater returns than investments in labor or other types of capital.

Still, the fact that a certain set of companies show high returns to investment in IT does not mean that these gains are translated into productivity improvement at the national level. It may be, as argued by Daniel Sichel (1997), that the impacts are mostly redistributional with the gains of some firms coming at the expense of their competitors. However, in a global economy, nations could benefit from IT investment just by making their firms more competitive against foreign firms. This would suggest a global zero-sum game, but with the potential for redistribution among nations. This prospect has serious implications for national policy because it means that nation states can benefit by increasing their investments in IT use, while countries that fail to do so will only get further and further behind with negative consequences for their economies. We will return to this issue later when we discuss the policy implications of the research.

EMPIRICAL RESEARCH AT THE COUNTRY LEVEL

The empirical research at the firm level is encouraging, but not sufficient to answer the productivity paradox. It is an issue articulated at the country level and therefore must be addressed at that level rather than just the firm level. Aggregating firm level data does not capture economy-wide effects. The firm level research only captures gains and losses of indivdual firms--not net gains to the economy. In addition, the firm level research has focused exclusively on large corporations, and therefore might not be representative of the entire economy. In addition, the firm level research has focused on corporations in the U.S. economy, which may not be representative of other economies. Hence, it is important to conduct top-down country-level analyses, and inter-country analyses. If the country level results are broadly consistent with the firm level findings, then this would boost confidence in those findings as well as directly address the productivity paradox.

Framework for Comparison of Country-Level Studies

We use the conceptual model (Figure 2) developed in Kraemer and Dedrick (1994) as a framework for new studies that have been undertaken with much larger databases than were used in that paper. The framework posits a virtuous circle between IT investments and economic factors. The first half of the virtuous circle is illustrated by the economic factors that drive IT investments: national wealth, wage rates, IT infrastructure and the price/performance of IT products. Growing national wealth provides the resources for investments in IT, both by businesses and by households. Increases in wages provide a greater incentive for organizations (firms, governments) to invest in IT, either to replace workers or to improve the productivity of workers. The presence of a high quality information infrastructure, in the form of communications networks and skilled human resources increases the potential value of IT investments and thus promotes such investments. Finally, the ongoing improvements in IT price/performance encourages continued investment to take advantage of ever greater capabilities of the technology at lower and lower prices.

[Insert Figure 2 here]

The curved lines in Figure 2 illustrate the other half of the virtuous circle, showing how IT investments can lead to economic growth. Increased labor productivity means an economy can support higher wages, which lead to increased personal income and consumption. Increased capital productivity supports higher returns on investments by organizations, and indirectly by individual investors (e.g. stockholders). Thus a given level of capital investment can result in higher returns in the form of economic growth. IT use might also have a negative effect by leading to the elimination of jobs, but these losses should be compensated by new employment created by economic growth. Also, new jobs are created directly in the area of IT use. These include user support, software programming, system integration and maintenance. Increased IT use also creates new information-based business opportunities in the economy and in the IT industry itself, especially in production close to use such as information services, thereby stimulating additional economic growth.

The key issue presented by the framework in Figure 2 is *whether IT investments result in improved national productivity,* which is also the crux of the productivity paradox. It is generally expected that IT use will increase national productivity in two ways. First, IT would improve labor productivity directly by substituting for labor or improving the productivity of workers. Second, it has been expected that IT would improve capital productivity by complementing other investments. The entire production system can be made more efficient through the use of computers for planning and coordination of activities within the firm and externally with suppliers and customers. In manufacturing, Dell Computer is well known for using "information as a substitute for inventory" throughout its value chain from inbound logistics through production to distribution (Kraemer, Dedrick and Yamashiro, 1998). In the service sector, American Airlines is able to better utilize assets such as airplanes, optimizing both capacity and ticket prices on flights through the use of computerized reservation and yield management systems. It is this pervasive ability of IT to enhance the productivity of capital and labor throughout the economy that creates the potential for significant improvements in national productivity.

In summary, economic factors and IT investment are interrelated. On the one hand, the remarkable price/performance improvements in IT over the last 20 years have stimulated companies and countries to invest more in IT use with the expectation of improved productivity and economic growth. IT use can in turn enhance productivity and stimulate the growth of IT-related industries, both of which will result in higher economic growth rates and better living standards.

Recent Empirical Studies

Previous country level studies of the economic impacts of IT have focused on the contribution of IT toward GDP growth using time series economy-level data for a single country. A limitation of this approach is that capital and labor tend to move together with each other and with the scale of the economy, making it difficult to obtain reliable and statistically significant results with a single country. In order to minimize this problem and to draw meaningful conclusions about the impact of IT investment at the country level, it is necessary to conduct empirical studies of multiple countries over time.

An important precursor to such cross-country analyses of IT payoffs was an inter-country analysis using a growth theory approach conducted by De Long and Summers (1991). The authors assessed the impacts of investments in machinery and equipment (M&E), and compared them to the impacts of investments in other types of capital. They found that over the twenty-five year period 1960-1985, each extra percent of GDP invested in M&E was associated with an increase in GDP growth of one-third of a percentage point per year. This was much stronger than the relationship found with non-equipment capital, suggesting that M&E were more productive than other capital. This paper provided a basis for differentiating returns on investment in different types of capital.

The first analysis of IT investment across countries was conducted by Kraemer and Dedrick (1994), who used data from 1984 to 1990 for twelve Asia-Pacific countries that represented different levels of economic development. IT investment was defined as total spending for computer hardware, software and services within a country. The study found a significant relationship between growth rates in IT investment and both productivity and economic growth at the national level. Due to the limited data involved, it was not possible to employ more sophisticated models that would control for the impacts of other variables. The study did, however, identify several factors that were strongly correlated with levels of IT investment, consistent with the model presented in Figure 2. These factors include wealth (GDP per capita), education levels, structure of the economy (share of employment in the service sector), and level of IT infrastructure (telephone lines/100 people).

A recent and comprehensive inter-country study by Dewan and Kraemer (1998) uses production function analysis with data from 36 countries for the period 1985-1993. The variables used in the analysis include: IT capital (defined as computer hardware, data communications, software and services), non-IT capital, labor (in billions of worker hours), and GDP per worker hour. Currency conversions are based on purchasing power parity, and capital (both IT and non-IT) is measured as stocks. Results are presented for the entire sample and for subsamples of developed and developing countries, both cross-sectionally and over time.

The analyses show that the returns on IT investment are positive and significant for developed countries, but not statistically significant for developing economies. The estimate of IT output elasticity is 0.036 (positive and significant) for developed countries, but statistically indistinguishable from 0 for developing countries (Table 1).[2]

[Insert Table 1 here]

These findings challenge the productivity paradox by showing that IT makes a positive contribution to the economies of developed countries. A possible explanation for the substantial contributions in developed countries is that new IT investments in developed countries can leverage off complementary investments in IT infrastructure, human capital, and information-oriented business processes, as well as earlier IT investments, to amplify the payoffs from IT. It is likely that the impact of IT must be attributable to the entire "system" of complementary investments, as opposed to IT alone. Accordingly, one explanation for the lack of significant returns on investments in lesser developed countries is the relative scarcity of IT infrastructure and other enabling investments. It may also be simply that investment levels in IT are too small to have a measurable impact on GDP.

New Empirical Research

For this paper, we have conducted new research that extends the approach used in Kraemer and Dedrick (1994) in two ways. First, we extend the earlier empirical analysis of Asia-Pacific countries with a larger sample of countries over a longer time period. Second, we use a growth theory approach to the same sample.

The extended empirical analysis correlates growth rates in IT investment with labor productivity growth for 43 countries from 1985 to 1995. With this much larger sample, we are able to produce more robust findings than in the earlier study and also control for growth in non-IT investment, as well as labor force growth and initial GDP per capita. Instead of simply measuring total IT and non-IT investment growth, however, we have chosen to use IT and non-IT investment *per worker* as the independent variables. Conceptually, this makes sense because the dependent variable is growth in GDP per worker, and we are thus measuring the capital investment in the same terms. Initial GDP per capita is included in order to control for the possibility that poorer countries will inherently tend to have higher or lower growth rates. Labor force growth is included to control for the possible decline in productivity as new, inexperienced workers enter the labor force. The formula is as follows:

Growth in GDP/worker = f(GDP/capita 1985, Labor force growth 85-95, growth in IT investment per worker 85-95, growth in non-IT investment per worker 85-95)

The aggregate sample data are presented in Table 2, along with a figure plotting IT growth rates and GDP growth rates (Figure 3).

[Insert Table 2 and Figure 3 here]

Sources of data are as follows:

- Growth in IT investment per worker--Calculated from data provided by IDC on total IT spending by country from 1985-1995, divided by number of workers, from the International Labor Organization's *Yearbook of Labor Statistics* (1997).
- Growth in non-IT investment per worker--Calculated by subtracting IT spending from total gross fixed investment, from the World Bank's *World Development Indicators* (1997), divided by number of workers.
- Initial GDP per capita--*World Development Indicators*
- Growth in labor force-- International Labor Organization (1997).
- Labor productivity growth--Calculated from GDP growth rates and growth rates in total labor force.

The statistical analysis regresses growth in IT spending per worker, growth in non-IT spending per worker, labor force growth, and GDP per capita in 1985 against the dependent variable labor productivity growth over the 1985-95 period. The results are shown in Table 3.

[Insert Table 3 here]

The results of the analysis show the following:

- Growth in IT spending/worker is significantly correlated (at the 10 per cent level) with labor productivity growth, even when controlling for the other factors. Figure 4 shows the partial regression of growth in IT spending/worker and GDP/worker growth .
- Growth in non-IT spending/worker is likewise correlated with productivity growth, and the relationship is stronger than for IT spending. The coefficients and t-stats for non-IT growth are much higher than for IT growth.

- When all four independent variables are included, non-IT investment is the dominant factor, but even controlling for non-IT investment, growth in IT investment is still positively and significantly related to both dependent variables.

[Insert Figure 4 here]

The fact that non-IT investment growth is the more important factor related to productivity growth is not surprising, as the size of non-IT investments dwarfs IT investments in all countries. In fact, as Table 2 shows, the ratio of IT to total investment in 1995 ranged across countries from 1.6% to 19.4%. However, it is noteworthy that even after controlling for differences in non-IT investments, growth in IT investment was still significantly correlated with productivity growth.

In a second extension of the analysis, we applied a growth theory approach as developed by Solow (1957), and applied by DeLong and Summers (1991) in their analysis of equipment and non-equipment investments and productivity growth. Here, the independent variables for IT and non-IT investment are no longer growth in spending, but total spending as a share of GDP. The relationship is as follows:

Growth in GDP per worker = f(GDP/capita 1985, labor force growth 85-95, IT/GDP, non-IT/GDP).

We ran a linear regression using all countries, with results shown in Table 4 and Figure 4. These results show a positive, significant relationship between non-IT/GDP and productivity growth, but no relationship for IT/GDP. Thus, unlike the production function analysis in Dewan and Kraemer (1998), but consistent with Pohjola (this volume), a growth theory approach does not find a significant relationship between IT investment and productivity.

[Insert Table 4 and Figure 4 here]

Based on the findings above, and on Dewan and Kraemer (1998), we find mixed evidence about returns to IT investment at the national level:

- Based on IT/worker, the relationship between IT and productivity is positive and significant
- Based on a growth theory analysis, there is not a significant relationship.
- Based on production function analysis, developed countries show strong evidence of payoffs from IT investment, while for developing countries there is no conclusive evidence.
- Returns to non-IT investment are positive and significant regardless of the model applied.

The lack of impact of IT investment in growth theory models is probably due to two factors. First, levels of IT investment are small relative to non-IT investment, as suggested by Sichel (1997). Only when IT accounts for a larger share of total investment are we likely to see statistically significant relationships.

Second, growth theory approaches are likely to require longer time series than were available for this analysis (1985-1995), in order to smooth out the effects of the business cycle. The growth theory analysis by Pohjola (this volume) is based on data from 1989-1996, which might have an impact on those results as well. By contrast, DeLong and Summers (1991) use data from 1960-1985 to show the impact of equipment investment.

It is unlikely that any particular empirical study will produce the incontrovertible proof of the payoffs from investments in IT and silence all of the skeptics. Rather it is the cumulative evidence from a number of studies, using different methodologies and different data sets, that is building a stronger case for the value of IT. Even the findings above based on growth rates of IT spending per worker, which includes data from 43 countries over 11 years, is far more convincing than the circumstantial evidence upon which the productivity paradox was initially based (e.g., Figure 1).

Finally, and suggestive of what future analyses might hold, Dewan and Kraemer's most recent analysis (Dewan and Kraemer, forthcoming) shows that the long term effects (Table 2, column 3) of IT across countries are greater than the cross-sectional effects. The year by year regressions from 1985-1993 (Figure 5) show that the returns from IT are increasing over time for developed countries. Moreover, they show the same pattern for developing countries after 1989 (though not the same magnitude). Thus, it appears that the important question for the future is not so much whether IT investments pay off on average, but what factors determine the value of IT at the national level, and what policies create the conditions under which the payoffs can be realized. We turn to this question next.

[Insert Figure 5 here]

IMPLICATIONS FOR NATIONAL POLICY

Payoffs from IT use

The evidence of empirical research shows that investments in IT use are correlated with increased productivity and economic growth for countries, and that the relationship is clearest for developed countries. They have invested in IT over a long period of time, have accumulated a substantial installed base, and have achieved positive and significant returns to IT. They also have made complementary investments in telecommunications and human resources which enable them to achieve these positive returns.

The logic of IT returns for lesser developed countries is the same as for the developed countries. However, because these investments are small relative to total GDP, the IT impact is less obvious in some studies. The fact that a particular analysis does not find a significant contribution of IT in developing countries does not mean that developing countries should shy away from IT investments. On the contrary, it is possible that there is some threshold of IT investments, or experience in use, that must be reached before these investments are measurable, or become as productive as non-IT investments.

The logic of technology use suggests that even widespread diffusion of new technology in a country is not necessarily sufficient for the benefits to be achieved. The recipient country must have the right environmental conditions, such as basic infrastructure, business practices and government policy, which reinforce the technology's deployment. Historical studies of countries that have been particularly successful indicate that such policies include promotion of computer use, promotion of education generally and of computer professionals in particular, enactment of low taxes and tariffs on computer imports, and telecommunications liberalization to lower costs (Dedrick, Goodman and Kraemer, 1995; Dedrick, Kraemer and Choi, 1996; Kraemer, et al., 1996).

The implication of these results is that developing countries can benefit by promoting IT use and creating the environmental conditions needed to support effective use. This is an especially significant conclusion because many developing countries' policies now promote IT production over use. However, this research on IT use and related research on computer production (Dedrick and Kraemer, 1998) suggest that the economy-wide benefits from IT use are likely to outweigh the benefits from production, which are limited to just one segment of the economy. The importance of IT use is becoming amplified by the process of economic globalization, which puts a premium on information and communications systems as the means to achieve linkages to international markets and global production networks.

Globalization, IT use and productivity

Participation in the global economy is seen by more and more countries as a path to economic success, in contrast to the emphasis placed on national self-sufficiency by many developing countries in past decades. Countries that had previously pursued protectionist strategies to nurture industrialization, such as China, Brazil and India, have lowered barriers to trade and foreign investment, and are privatizing and deregulating important industry sectors. Meanwhile, multinational corporations are looking increasingly to developing countries for new markets and low cost production sites, creating new opportunities for those countries to participate in the global economy.

The potential benefits of globalization to developing economies are great, including access to capital, markets and technology. Countries such as Singapore, Taiwan, Thailand, Malaysia and Ireland have achieved rapid growth and development through outward-looking economic strategies, often in partnership with MNCs. However, the benefits are not automatic, and there are costs to liberalization also. Domestic companies can be destroyed by foreign competition at home, and MNCs may simply import goods to the local market without producing, exporting, or bringing in any technology. And if they do produce and export, they may only perform the lowest value assembly work, creating jobs with very low pay and sometimes poor working conditions.

In order to benefit from globalization, and from foreign competition in the domestic market, developing countries need to establish competitive capabilities beyond cheap labor. These can take the form of educated workers, high quality infrastructure, local R&D capabilities, and strong entrepreneurial skills. Another competitive advantage is the ability to use IT effectively. When markets are opened up, domestic companies face competition from MNCs who bring in the most advanced information systems. In order to compete, domestic firms can develop partnerships with those MNCs to gain access to the technology, as a number of Mexican and Brazilian banks and retailers have done in recent years. They can work with leading information services providers in order to develop their own systems, or in some cases they may decide to outsource their information systems altogether. Whatever strategy is used, staying competitive requires investments in IT to develop world class information systems.

In addition to staying competitive in the domestic market, companies that make these investments are also setting the stage for competing in international markets. The global production networks of many industries (e.g., PCs, semiconductors, automobiles) are moving quickly to integrate the entire supply chain electronically. Electronic data interchange was a first step, but now MNCs are linking their design, procurement, manufacturing, logistics and marketing through Internet-based technologies. Even low-technology industries such as textiles and footwear are following suit. Internet commerce will make it possible for even small companies in remote locations to market their products and services around the world. Companies and countries that hope to participate in these production networks will need sophisticated IT skills and good information infrastructures. Those that have made the investments and developed the capabilities will benefit from globalization, while others will be left out.

Production vs. use

The foregoing analyses of the payoffs from IT investment have focused on the *use* of IT as a productivity tool throughout the economy. There are also benefits at the national level from local *production* of computer hardware, software and services. In fact the benefits from production are often more visible than those from use. The benefits from production include jobs ranging from unskilled assembly to highly skilled design and engineering. They also include participation in a dynamic, high-growth industry with strong export potential and creation of national technological capabilities.

Evidence of the value of IT production in the United States has recently been documented in a 1998 report by the U.S. Department of Commerce. The report estimates that IT industries (computer hardware, software and services, communications equipment and services) accounted for 7.5% of the U.S. economy and 15.8% of GDP growth in 1996. When adjusted for falling prices, the contribution is estimated to be even greater, accounting for 34.7% of GDP growth in 1996. It is also argued that IT production contributes to lower inflation rates, since a growing share of economic output is in an industry marked by rapidly falling prices. The report argues that actual inflation, which was 2.0% in 1997, would have been 3.1% without the effect of the IT industry's declining prices. Finally, the IT industry, including telecommunications, employed 7.4 million workers in 1996 (6.2% of total employment), with an average annual wage of $45,737, compared to $28,000 for all private employees.

Outside the U.S., other countries have had equally impressive results from IT production. The IT industry is a major source of economic output, exports and jobs in countries such as Japan, Taiwan, Singapore, Hong Kong, China, Korea, and Ireland, thanks mainly to opportunities created in the PC hardware industry beginning in the early 1980s (Dedrick and Kraemer, 1998). Countries such as India, China and the Philippines are also finding opportunities in the software industry thanks to large supplies of programmers. It is not surprising that policymakers are attracted by the possibility of developing national computer industries, and that many developing countries (e.g., Brazil, Mexico, Malaysia, Thailand and China) have used various policy tools to encourage investment in IT production.

Creating a local IT industry is not a simple matter, however, especially for newcomers to the industry. While a number of new countries entered the industry during the PC revolution of the 1980s, other countries such as Brazil and Mexico had little success, and some earlier industry participants, including many European countries, were squeezed out. Even Japan and Korea have had limited success in computers (as opposed to components) outside their own markets.

If anything, the opportunities for newcomers are more limited today. Industry segments such as microprocessors, operating systems and packaged business applications are virtually closed off because the standards are set by the leading players in the IT industry, mainly U.S. companies such as Intel and Microsoft. Other segments of the hardware industry require large capital investments, economies of scale, and specialized skills that few countries can hope to achieve. Moreover, many of these opportunities have already been preempted by earlier entrants such as Singapore, Hong Kong, Korea, Taiwan, Ireland and Israel. Only a newcomer with a large domestic market and proximity to an existing supplier base is likely to enter these industry segments. China is doing so by negotiating with multinationals for production and technology transfer in return for market access. It also happens to be located near the vast supply chain that spans East Asia. Some countries are offering expensive incentives to attract foreign investment in hardware production, but it is questionable whether they can catch up at this point. And even if they are successful in attracting foreign investment, the resulting industry is likely to have limited value added and few opportunities for local companies to participate.

Finally, production benefits only one industry sector—the IT sector, while IT use can benefit all industry sectors. So if local production is promoted at the expense of domestic users, for example through import barriers that raise prices, the bargain is probably a bad one for the economy as a whole. Given the choice between promoting production or use, we would argue for use, especially in countries that are not already part of the global production network of the computer industry. Fortunately, however, the choice does not have to be so stark in most cases.

In fact, there is a policy option that simultaneously encourages IT use while also creating opportunities to develop a local industry—that is, production close to use.

Production close to use

Most national policies to promote computer production have focused on hardware, which is the most tangible segment of the industry. However, the fastest growing segments of the computer industry for over a decade have been software and services (Table 5.)

[Insert Table 5 here]

The software and services industries offer some specific advantages over hardware production. First, while some parts of the software industry are dominated by multinationals, there are still many opportunities to develop niche products without competing directly with Microsoft, Oracle, SAP and other large companies. These can be products developed for local markets that meet the needs of local language, culture and business environments. The services business offers even more compelling opportunities, as services usually must be provided locally rather than being imported. They also require continuous interaction between local users and providers, and can benefit users as well as providers, helping countries realize the payoffs from IT use.

Figure 6 shows how information services such as systems integration, outsourcing and network services can serve as a link between production and use. These linkages can help local users apply the technology more effectively, and can create business and employment opportunities for local people in developing countries. These businesses are especially appropriate for developing countries because there are lower entry costs, so local companies can start small and grow at a pace that is supportable by their own finances and capabilities.

[Insert Figure 6 here]

All of this does not mean that developing countries cannot participate in the hardware industry. In fact, as PC companies move toward build-to-order production, there are new opportunities for countries that have, or are close to, large markets. Those countries then may be able to attract suppliers to support PC production and create a competitive industry cluster for IT production. But even those countries should not be so focused on hardware that they ignore the great potential of software and services. Countries just trying to enter the industry with limited resources to invest should look carefully at whether efforts to promote hardware production would have the same payoffs as promotion of IT use and production close to use.

Development Strategies

Effective national strategies to realize the benefits of information technology need to cover three areas: promoting use, promoting production, and developing national capabilities. These policies are much more effective when they are closely coordinated and receive support from the highest levels of government, as is the case in Singapore and Taiwan, rather than becoming the object of interagency struggles for power and resources, as in Japan, Korea and many other countries (Dedrick and Kraemer, 1998). They will also be more effective when developed in close consultation with the private sector, including both local and multinational firms, and with domestic and foreign experts from academia and industry.

Promoting Use

One of the best ways to promote IT use is to not create barriers to use. Any government policy that makes computers more expensive will discourage use and reduce the possible benefits of IT. Simply lowering tariffs and taxes, eliminating other trade barriers, and encouraging competition in distribution channels will help promote use as much as any specific efforts to encourage use.

Governments can do more than just get out of the way, however. One thing they can do is to become sophisticated IT users themselves. The key here is not just spending a lot on IT, but actually developing advanced applications of the technology and becoming a model for the private sector. Many government bodies are now setting up web sites where citizens can get information about services, download forms, gather data, and communicate with officials. Governments can encourage use of these services by providing Internet access in libraries, schools and other public facilities. A further step is to allow (or in Singapore's case, require) companies to transact business with the government electronically. This can involve things such as tax filings, customs documents, and permit applications. Another important way to promote use is through the schools. Putting computers and Internet access in school rooms, providing necessary support services and training teachers in the use of IT in the class room can not only improve education, but it creates a new generation of children who are comfortable with using the technology.

There is a great deal of room for countries to find innovative uses for information technologies that fit their own situations. Applications such as geographical information systems can help countries protect natural resources and plan for growth. Distant learning by satellite is a way of supporting education in countries with remote rural populations. CD-ROMs can be used to archive national treasures and make them available throughout the country and abroad. Setting up local telecommuting centers can help reduce traffic in congested cities. Governments can provide resources to develop and deploy such applications, and can amplify their impacts by working with the private sector. In some cases, such applications can be turned into commercial products for domestic and even international markets.

There are other more controversial issues that bear directly on the use of IT. One is the desire of governments to control the type of information available to citizens. Countries as diverse as the U.S., Germany, China, France and Singapore have all tried to place restrictions on access to content, whether pornography, anti-government information, or foreign language content. Whether the desire is to protect children, preserve national culture, prevent terrorism or squash political opposition, policies that limit access to information will discourage use of the technology, especially as the Internet becomes a global medium for both information and commerce. Other concerns include privacy, access rights, and intellectual property rights. Information technology can clearly provide great benefits, but its effects can also be destabilizing to governments, businesses and other established regimes, and these issues cannot be ignored if countries hope to achieve the benefits of IT use.

Promoting production close to use

Most developing countries should focus on production close to use, and avoid the temptation to invest heavily in creating a hardware industry. If a country is not strategically located near a major market and supplier base, it has little chance to compete in hardware. Even for those few countries, the prospects of success might be quite limited due to the locked-in position of existing producers, who have developed specific capabilities and infrastructure needed for specific industry sectors, such as Singapore in disk drives, Korea in DRAMs and Taiwan in PCs and peripherals.

A more interesting proposition is how countries can promote production close to use. There are fewer obvious cases of successful government policies in this area, as it is only recently that some countries have started to promote software and services production. Also, most previous academic research on the computer industry has emphasized computer hardware or electronics more broadly. Only a few studies such as Schware (1992) and Carmel (1995, 1997) have focused on the software industry. Perhaps the most valuable contribution to this area is Schware's notion of "walking on two legs" which argues that countries should target production and use in tandem, focusing on the interaction between production and use in the software and services industries.

Schware's argument, which is expanded upon in Dedrick and Kraemer (1998) and in Figure 6, is that the interaction between producers and users is critical to the development of certain types of software and information services. The question is what types of policies can facilitate this interaction and provide resources needed by local companies to participate in these markets. Some recommendations are as follows:

- Promote small business IT use. A growing, sophisticated user base is the best resource for software and services companies. In particular, smaller vendors benefit from use by small businesses, who traditionally turn to those vendors to set up and maintain systems and networks, design web pages, provide Internet services, and design custom software to solve specific problems. An example of a policy to promote small business use and help local developers can be seen in Taiwan, where the government is helping software companies develop applications for small businesses such as restaurants and bicycle shops, which often have multiple outlets. It is hoped that these applications can be eventually sold around the country and to Chinese language markets around the world.
- Provide financial support. Software and services companies often fail to survive even when they have good people and technology simply because they are starved for capital. Very few countries have well-developed venture capital markets or over-the-counter stock exchanges, and developing countries do not have many wealthy "angels" who are familiar

with the industry and willing to fund startups. Governments can provide or guarantee low-interest loans in relatively small amounts that are appropriate for small companies. They can also provide direct grants to promising companies. In both cases, the key is having the capability to make sound judgments about the companies' business plans, management skills, and market prospects.

- Encourage partnerships between local firms and multinationals. One of the best ways for local firms to get established is to operate as subcontractors for multinational corporations. Local firms are often used for software localization and maintenance, product support, marketing, and other services. Working with world class companies helps develop the skills and knowledge needed to grow and compete, and also can provide a reliable revenue base to support that growth. Governments can offer incentives to multinationals to participate in partnership programs, and also provide resources directly.

Developing capabilities

In order to support both IT use and production, countries need to develop capabilities in the form of human resources, information infrastructure, R&D, and business skills. At one level, there is a need to develop a broad base of basic capabilities, such as raising the level of education for the population as a whole, and putting in transportation and telecommunications infrastructure throughout the country. In the long run, IT will benefit developing countries to the extent that they can achieve the widest possible diffusion of the technology, and create the broadest base of capabilities to support IT use and production close to use.

On the other hand, there is also a need to make focused investments in high level capabilities, especially in the short term. This includes training IT professionals, including computer scientists and engineers, electronics engineers, programmers and analysts, and management information systems specialists. A cadre of such highly skilled professionals can serve as a conduit to bring leading technologies into a country and facilitate the local production and use of IT. The benefits of computers in schools, businesses and government cannot be realized without people who understand the technology and can adapt it to the needs of local users. Likewise, creation of a local IT industry is impossible without engineers and other professionals to develop products and services and techologically savvy business people to start and manage IT companies.

There is also a need to invest in specialized information infrastructure, such as high-speed Internet backbones and satellite uplinks to allow researchers and business people to have access to the most advanced global information networks. For instance, India has created a high-speed network in the Bangalore area, complete with satellite uplinks, to support the fast-growing software industry in that region. Some Caribbean countries have also developed high-speed connections to the U.S., which are used for remote data processing, call centers and other information services.

These investments in specialized skills and infrastructure may initially compete for funding with other priorities such as basic education and infrastructure. One argument for diverting some funds to such focused investments is that those investments will create the seed for building broader capabilities. For instance, people who receive advanced degrees in science and technology can serve as teachers and professors in local schools and universities and pass on their knowledge to large numbers of students. They can also start new businesses, or help manage existing businesses, that create local employment. Advanced information networks can also serve as a core for Internet diffusion, by creating the high-speed backbones and international connections needed for general purpose access.

As mentioned above, one way that countries can support some of these focused initiatives is through partnerships with multinational corporations. These partnerships can provide funding, but more importantly they provide access to advanced knowledge and technology. The Singapore government has specialized in such partnerships, with companies such as IBM, Apple, Siemens and Texas Instruments, as well as with some foreign government institutions. Taiwan worked with MNCs and foreign experts to build government research labs and create companies to spin off technologies developed in those labs.

Private sector partnerships and joint ventures can also help develop capabilities, as in the case of Mexican banks that are entering joint ventures with U.S. banks and gaining access to their knowledge of how to build and use information systems. Such relationships not only bring in technology, but they give local people the chance to work with outside experts, sometimes by travelling abroad for training and work experience. When combined with graduate education in leading U.S. and European universities, this experience provides local professionals with both new knowledge and new perspectives on the global economy.

CONCLUSIONS

Empirical research on a broad cross-section of countries provides strong evidence that investments in information technology do pay off in greater economic growth and productivity. These findings should encourage developing countries to promote IT investment and to develop the human resources and infrastructure needed to support effective use of the technology. Building upon earlier studies at both the company and country level, this research further challenges the productivity paradox by refuting the basic claim that there is no correlation between IT spending and productivity growth.

As countries look at how they can realize the potential benefits of IT, they need to weigh the value of promoting IT production and use. While there are good opportunities to be found as a producer in such a fast growing industry, many segments of the industry are dominated by powerful incumbants and present very high entry barriers to newcomers. Attempting to enter such segments through protectionist policies is unlikely to succeed, and will exact a high cost to users by raising prices for IT. Other policies such as providing financial incentives to producers might be more successful, but in many cases developing countries get little more than low value assembly operations in return for costly incentives. A few new countries might break into high volume hardware production, but most simply don't have the resources.

Fortunately, there is a segment of the industry that presents good opportunities for developing countries, while also helping to support better use of IT. This segment, which consists of services and specialized software, is actually the fastest growing part of the industry, and offers many openings for small niche players. Some of these niches might eventually grow into large markets, and those small players can develop globally competitive products and services. Such production close to use is a good fit for many developing countries, offering business opportunities for local firms and jobs for skilled IT professionals who might otherwise have to go abroad to use their skills. The most effective policies for developing countries are those that promote use and production close to use, and those that build national capabilities. If these policies are developed in close consultation with the private sector and academic institutions, and if the efforts of related government agencies can be coordinated so that they complement, rather than compete with each other, the result can be a rapid diffusion of the technology, with broad benefits for the country.

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ENDNOTES

[1] The standard errors are quite large in some of these studies. Also, when adjusted for the rapid depreciation of computer hardware, the net returns are more modest.

[2] These estimates are robust in that they hold up to different statistical models (random versus fixed effects), different statistical tests for errors in variables, autocorrelation and simultaneity, and different definitions of the IT variable.

TABLES AND FIGURES

Table 1. Production function estimates based on different models

	Random effects model (total regressions)	**Fixed effects model (within regressions)**	**Long run effects (between regressions)**
Developed countries			
βIT	0.036***	0.032**	0.277***
	(2.616)	(2.549)	(7.508)
βK	0.245***	0.151***	0.095
	(4.856)	(2.585)	(1.566)
βL	0.687***	0.678***	0.637***
	(12.086)	(7.120)	(18.031)
DF	176	154	18
R^2	0.901	0.861	0.996
Developing countries			
βIT	-0.036**	-0.024*	0.080
	(-2.449)	(-1.699)	(0.670)
βK	0.498***	0.529***	0.412*
	(10.244)	(10.867)	(2.184)
βL	0.368***	0.541***	0.344***
	(5.149)	(3.738)	(3.277)
DF	106	92	10
R^2	0.928	0.924	0.899

Year dummies are included in all regressions except the between regressions. T-statistics are in parentheses, and ***, **, and * indicate significance at 1%, 5% and 10%, respectively.

Source: Dewan and Kraemer, 1998.

Table 2. Descriptive statistics of 43 countries in the analysis

Indicator (in millions)	*Mean*	*SD*	*Median*	*Min*	*Max*
GDP, 1995 in US$	$522,106	$1,243,636	$155,371	$12,366	$6,952,020
Population, 1995	87	220	21	3	1,200
Labor Force, 1995	43	118	9	1	709
IT investments, 1995 in US$millions	$11,058	$35,389	$1,927	$126	$224,298
Percent IT investment of total investment	7.5	4.6	5.6	1.6	19.4
Percent IT investment of GDP, 1995	1.5	.8	1.5	.4	3.2
GDP growth, 1985-1995 (CAGR)	3.0	3.0	2.5	-3.9	10.1
Labor force growth, 1985-1995 (CAGR)	1.5	1.2	1.3	-.5	5.2
IT investment growth, 1985-1995 (CAGR)	17.3	5.8	16.0	8.0	33.1
Non-IT investment growth, 1985-1995 (CAGR)	8.2	7.3	9.0	-14.4	21.2
Productivity growth, 1985-1995 (CAGR)	1.5	2.6	1.2	-3.9	8.3

Table 3. Results of regression for extended analysis
(dependent variable is growth in GDP/ worker, 1985-1995).

Independent variable(s)	**Coefficients**	**t**	**Significance**
Constant	-.0218	-1.667	.104
GDP per capita, 1985	.00000006	.093	.926
Labor force growth	.0032	1.111	.273
Non-IT/worker growth	.256	5.595	.000
IT/worker growth	.0942	1.706	.096
R^2	.497		
N	43		

Table 4. Results of regression for the growth theory approach

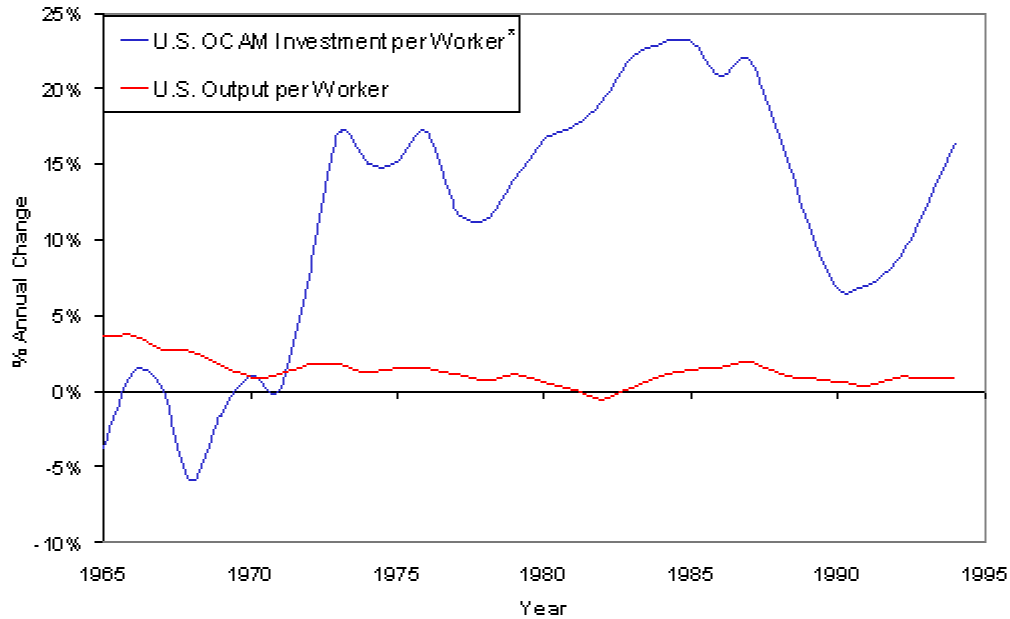
Independent variable(s)	**Coefficients**	**t**	**Significance**
Constant	-.0517	-3.128	.003
GDP per capita, 1985	-.00000001	-.002	.991
Labor force growth	.00036	-.002	.896
Non-IT/GDP	.290	5.180	.000
IT/GDP	.436	.634	.530
R^2	.422		
N	43		

Table 5. Computer industry growth rates, 1985-1995

Industry segment	CAGR (%)
Hardware	11.0
Software	15.9
Services	20.9

Source: McKinsey & Co. 1996 Report on the Computer Industry

Figure 1. The Productivity Paradox of IT
(Annual Change in Office, Computing & Accounting Machinery Investment and Output per Worker for the U.S. over 1965-1994)



Source: Bureau of Economic Affairs.
* OCAM is the BEA's "Office, Computing & Accounting Machinery."

Figure 2. Economic Returns from IT Investments.

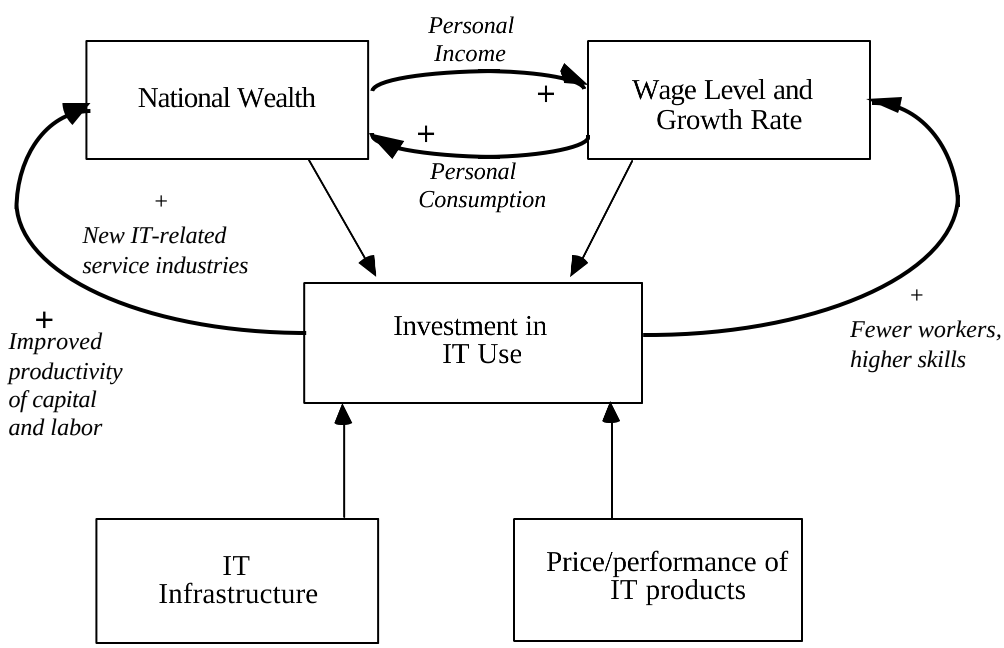


Figure 3. Correlation between IT investment growth and GDP growth, 1985-95

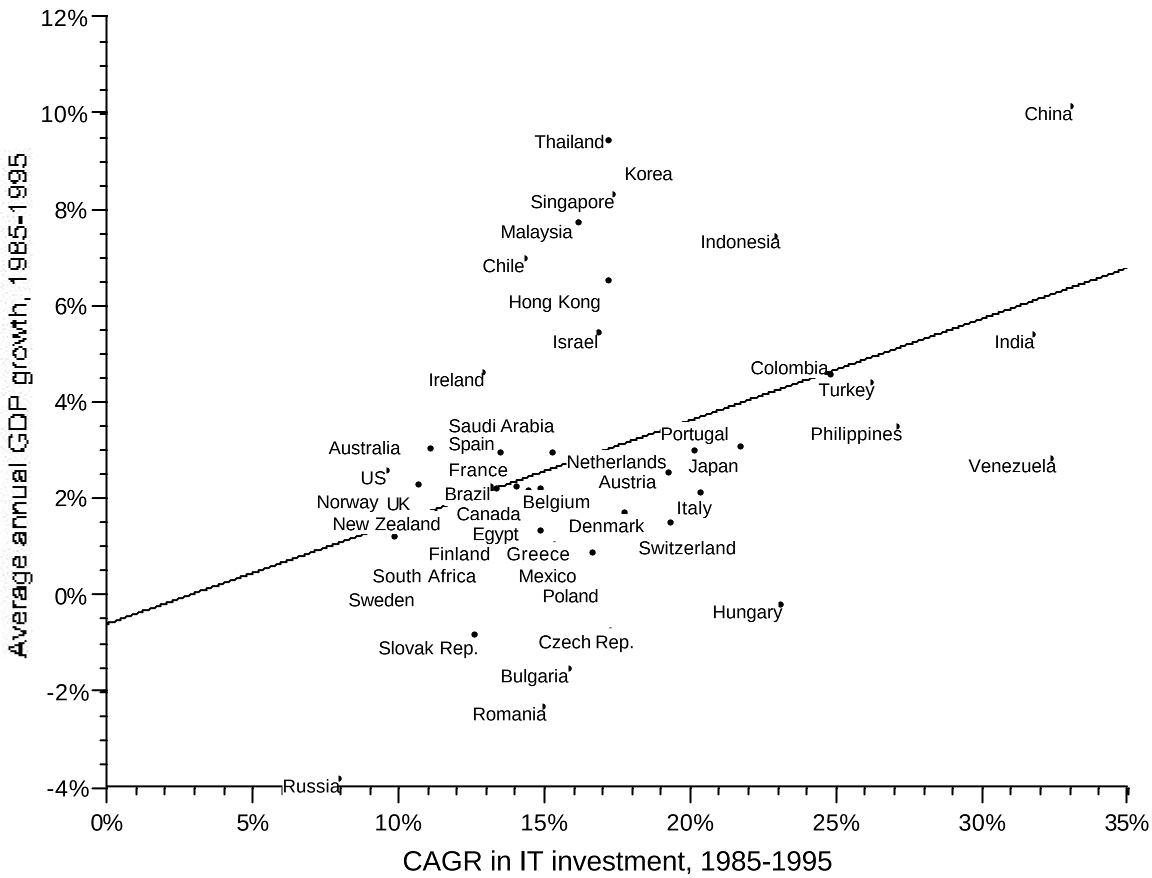


Figure 4. Partial regression of growth in IT investment/worker and GDP/worker

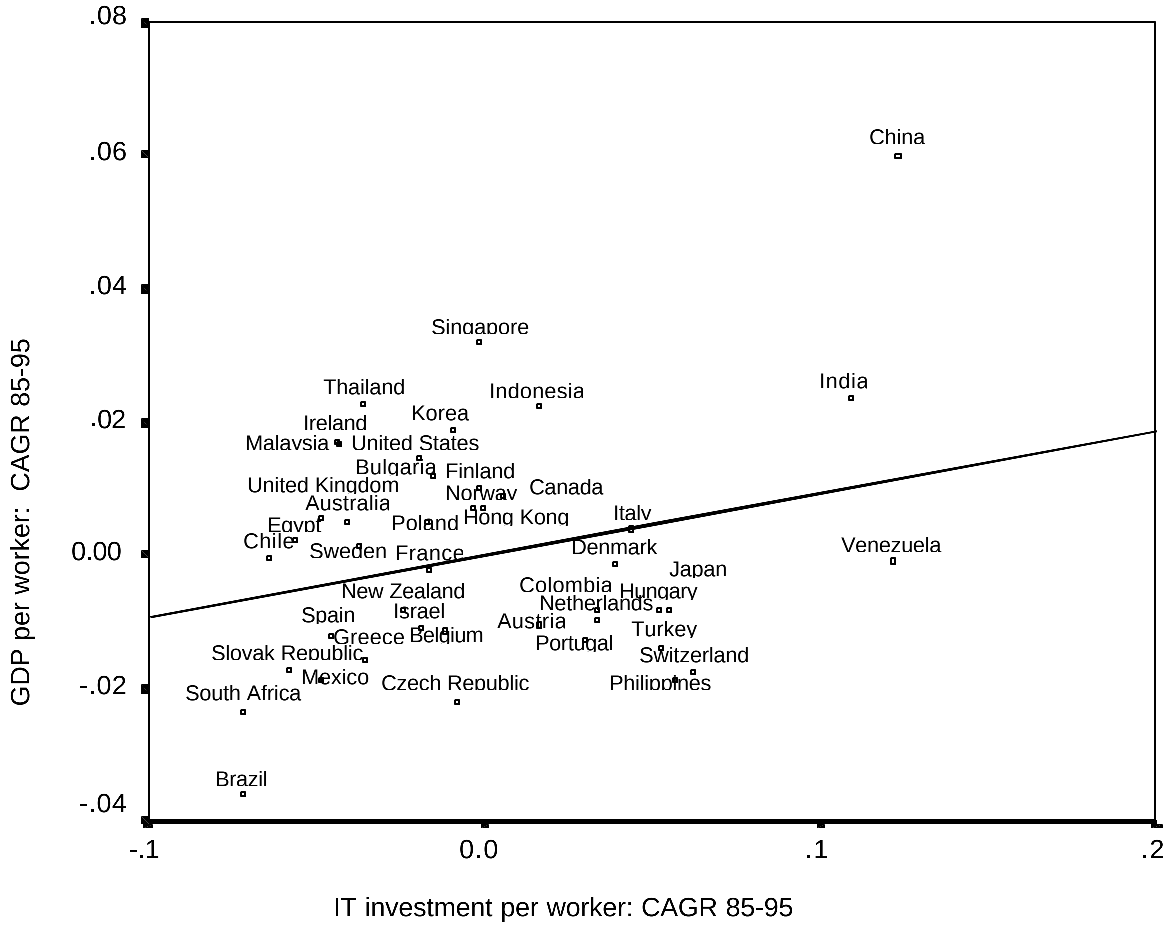


Figure 5. Year-by-year returns to IT capital: developed and developing Countries

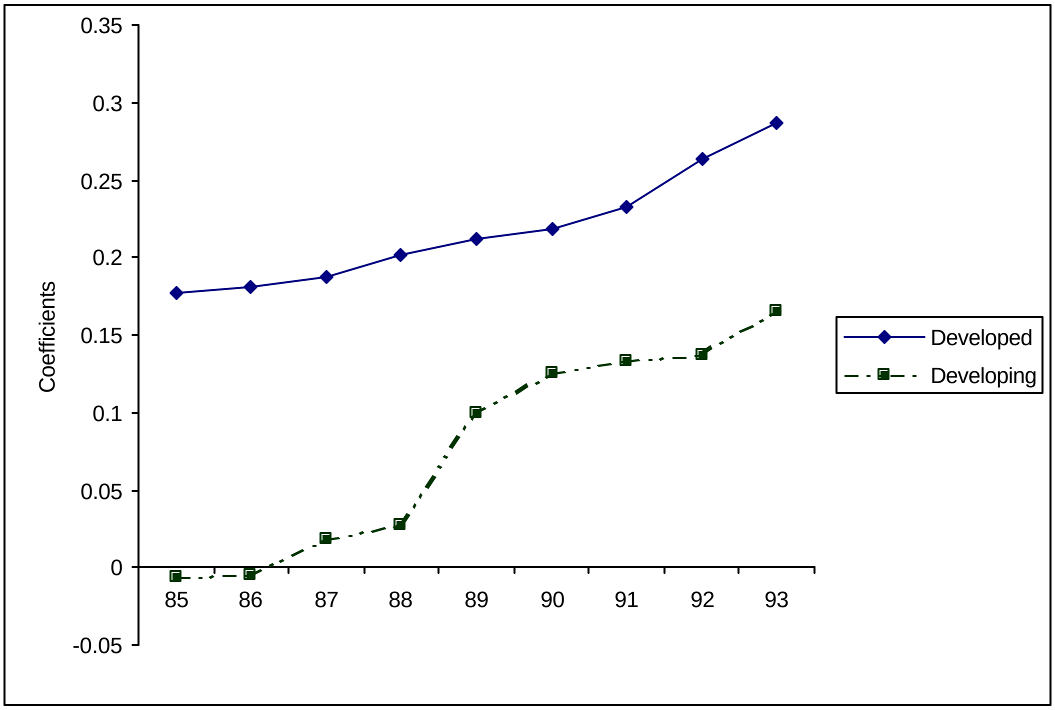
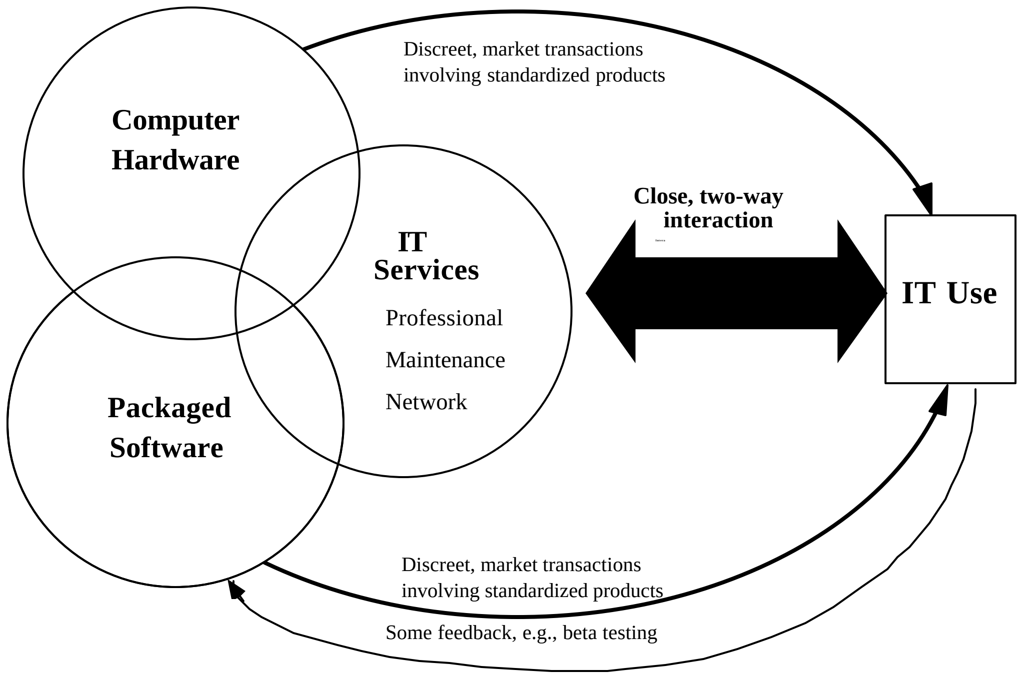


Figure 6. Information Services as Link Between Production and Use



Appendix table

Data table for Figure 5. Year by Year Regressions using Seemingly Unrelated Regression

	1985	1986	1987	1988	1989	1990	1991	1992	1993
Developed countries									
β_{IT}	.0177***	0.181***	0.188***	0.201***	0.212***	0.218***	0.232***	0.264***	0.287***
	(6.523)	(6.839)	(7.181)	(7.470)	(7.692)	(6.789)	(6.407)	(6.623)	(6.886)
β_K	0.222***	0.212***	0.191***	0.185***	0.172***	0.145**	0.152**	0.134**	0.108*
	(4.082)	(4.098)	(3.759)	(3.571)	(3.286)	(2.599)	(2.554)	(2.222)	(1.841)
β_L	0.607***	0.617***	0.632***	0.629***	0.629***	0.638**	0.620***	0.603***	0.598***
	(15.062)	(16.219)	(17.104)	(16.855)	(16.952)	(16.717)	(15.806)	(15.623)	16.683)
DF	162								
R^2	0.977								
Developing countries									
β_{IT}	-0.006	-0.005	0.019	0.028	0.10***	0.125***	0.133***	0.137***	0.165***
	(-0.286)	(-0.207)	(0.727)	(1.331)	(5.319)	(4.998)	(4.763)	(5.117)	(4.915)
β_K	0.514***	0.524***	0.505***	0.484***	0.398***	0.368***	0.365***	0.371***	0.383***
	(6.477)	(6.205)	(6.112)	(6.798)	(7.125)	(5.701)	(5.155)	(5.315)	(5.402)
β_L	0.297***	0.293***	0.300***	0.313***	0.351***	0.341***	0.324***	0.317***	0.303***
	(4.546)	(4.140)	(4.317)	(4.925)	(6.655)	(5.606)	(4.869)	(4.772)	(4.718)
DF	90								
R^2	0.976								

Note: t-stats in parentheses
Source: Dewan and Kraemer (forthcoming)