IT and Productivity in Developed and Developing Countries

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Abstract

Previous research has found that IT investment is associated with significant productivity gains for developed countries but not for developing countries. Notwithstanding the lack of evidence of productivity gains, developing countries have increased their investment in IT dramatically. There is a need for new research to study whether the investment has begun to pay off in greater productivity for developing countries.

We analyze new data on IT investment and productivity for 41 countries from 1985-2004, and compare the results from 1994-2004 with the years (1985-1993) covered in earlier research. We find that developing countries have achieved significant productivity gains from IT investment in the more recent period as they have increased their IT capital stocks and gained experience with the use of IT. We also find several complementary factors that have an impact on the relationship of IT to productivity, including education, telecommunications pricing and investment, and inward foreign investment.

IT and Productivity in Developed and Developing Countries

1. Introduction

The question of whether IT investments lead to greater productivity has been studied extensively at multiple levels, with strong evidence that the returns to IT investment are positive and significant for firms (e.g., Brynjolfsson and Hitt, 1996, Lichtenberg, 1995; Dewan and Min, 1997), for industries (Jorgenson and Stiroh, 2000; CEA 2001; Bosworth and Triplet, 2000) and for the U.S. economy (e.g. Jorgenson 2001; Oliner and Sichel, 2000).

Research at the cross-national level has found that IT investment is associated with significant productivity gains for developed countries but not for developing countries (Dewan and Kraemer, 2000; Pohjola, 2001; Schreyer, 2000). Nonetheless, developing countries have increased their investment in IT dramatically. For instance, China had fewer than 10 million PCs in use in 1998 and barely 1 million Internet users (Dedrick and Kraemer, 1998). Today, China is the world's second largest market for PCs, with sales of about 40 million in 2009 (Zhoudong, 2010) and the largest Internet user, with over 400 million users (Internet World Stats, 2010). Similar rapid growth in places such as India, Latin America, Southeast Asia and Eastern Europe have transformed the landscape for IT use in developing countries. Given all of this IT investment, there clearly is a need for research to study whether the investment has begun to pay off in greater productivity for developing countries. To our knowledge, there have been no cross-country studies using datasets that extend beyond the mid-1990s.

In addition, most prior studies employed a production function approach with labor, IT capital and non-IT capital as inputs, and GDP as the output. They did not incorporate complementary assets or government policies that might affect the productivity impacts of IT.[1] Yet factors such as human capital, openness to foreign investment, and telecommunications infrastructure and pricing are important variables that may directly interact with the use of IT to improve productivity. These factors already have been shown to be related to levels of IT investment at the country level (Shih et al., 2007, 2008). It is important to determine whether these factors will also have an impact on productivity gains from IT investment. If so, governments and firms will have guidance to make investments that are most likely to complement their ongoing IT investments. Researchers will have evidence to better understand the nature of complementarity among IT and other assets and the ability to develop more fully-estimated models of the impacts of IT investments.

In this study, we utilize new data on IT investment and productivity for 41countries from 1985-2004, and compare the results from 1994-2004 with the earlier years (1985-1993) that were covered by

[1] An exception is Pohjola, 2001, which incorporates human capital in an empirical study of IT and productivity across 39 countries.

Dewan and Kraemer (2000). The goal is to find out whether developing countries have been able to achieve significant productivity gains from IT investment in the more recent period as they have increased their IT capital stocks and gained experience with the use of IT. We also incorporate a set of complementary factors missing from previous studies, including telecommunications investment and prices, human resources, and foreign direct investment, to determine whether these factors have an impact on the relationship of IT to productivity.

2. Literature Review

To frame the analysis, we review the country-level literature on IT and productivity and the factors potentially influencing productivity impacts. Figure 1 provides an overview of the framework derived from the literature review discussed below. Moving from left to right, the framework identifies the various inputs (labor and capital) to production in the economy, complementary factors of production that influence production, and the contribution of the inputs to outputs (value added, gross domestic product) and to various economic outcomes (labor productivity, economic growth).

[Insert Figure 1 here]

2.1 IT and productivity

Most of the research on IT and productivity on an international or cross-country basis, involving both developed and developing countries, was conducted in the 1990s. The consistent finding in these studies is that IT investment is associated with significant productivity gains for developed countries but not for developing countries (Dewan and Kraemer, 2000; Pohjola, 2001; Schreyer, 2000).

At the time of these studies, various explanations were offered for the lack of productivity gains from IT investment in developing countries. One was that developing countries lacked complementary assets such as human capital and telecommunications infrastructure needed to support IT use (Pohjola, 2001). Another was that developing countries had less experience with IT, and as a result had not learned to use IT effectively, or to make complementary organizational and process changes needed to achieve productivity gains from IT (Dewan and Kraemer, 2000). In addition, the very low levels of IT capital stock in developing countries meant that it was difficult to capture the impacts of IT on productivity in standard production function models.

The data in the various studies came mostly from the late 1980s through the mid-1990s, a time when most developing countries had very limited IT experience and low levels of IT capital stock. Investments in IT have grown steadily since then, and in some cases accelerated greatly, raising the IT capital stock of developing countries. This makes it more likely that real productivity impacts have been achieved from these investments and that econometric models will now capture these impacts.

2.2 Factors influencing productivity impacts

The cross-country productivity studies generally do not examine the factors that might influence the productivity impacts of IT. However, firm level studies have shown that there are considerable differences in productivity among firms and that they can be partially explained by complementary investments and management practices (Loveman, 1994; Brynjolfsson and Hitt 1995; Bresnahan et al. 2001). It is likely that country-level complementary assets and government policy might explain country differences as well. Given that there are no previous such countries studies, we identify country factors from studies of IT diffusion and use on the theory that greater IT penetration throughout the economy is likely to influence productivity impacts. The factors identified in the literature can be classified as complementary assets (human capital and telecommunications infrastructure) and government policy (openness to the global economy and cost of telecommunications).

The availability of complementary assets that support the use of IT will likely influence the level of productivity related to IT investment in a country. One resource necessary to gain from IT use is *human capital,* people who know how use, support and extend the technology to new uses. Such knowledge and skill is gained from general education as well as IT-specific knowledge in areas such as computer science and management of information systems. IT has been shown to be a skill-biased technology whose value is closely linked to the skill levels available to the firm or country (Krueger 1993, Bresnahan et al. 2002). Educated workers not only have the skills to use computers, but are generally more flexible and more readily adapt to the introduction of new technologies (Bartel and Lichtenberg 1987, Robison and Crenshaw 2002). Several multi-country empirical studies have found a strong association between the level of education and IT investment (Pohjola, 2001; Shih et al., 2007; Caselli and Coleman, 2001). A specific study of developed and developing countries found tertiary education rather than average years of schooling to be especially important for internet diffusion in developing countries, but less so for developed ones (Kiiski and Pohjola, 2001). Tertiary education provides the higher level knowledge and skill that is key to technology use and support within organizations (firms, governments, schools) whose use of IT is critical to productivity gains at the national level. They also are the vehicles through which technology diffuses to individuals and households in the economy (Venkatesh 1996),where additional productivity gains may be realized.

Another important complement to computer use is *telecommunications infrastructure*. Much of the value of computers comes when they are networked via the Internet, organizational intranets, and other types of networks in national and global supply chains. Such networks require an underlying telecommunications infrastructure to link individuals and organizations. Previous empirical studies show a positive association between IT diffusion and the various measures of telecommunications infrastructure (Shih et.al., 2007, Oxley and Yeung 2001, Robison and Crenshaw 2002; Kaufman, et al, 2009). Research also shows that there is an interactive effect between computer and network use, with greater PC use leading to greater Internet use and Internet use in turn influencing greater PC use (Dewan et al, 2010). This complementary co-diffusion effect is stronger for developing countries than for developed ones and might contribute to productivity gains for developing countries.

In terms of government policy, one factor that is likely to influence the impacts of IT on productivity is a country's *openness to the global economy,* which can provide access to a broad range of technical and managerial knowledge that exists beyond its borders (Grossman and Helpman 1991, Ben-David and Loewy 2000). Foreign trade and investment can provide access to such knowledge by providing channels through which knowledge can flow between firms and individuals in different countries (Coe et al. 1997). Openness to foreign investment can attract multinational corporations who introduce new uses of IT and transfer systems and knowledge to local employees in developing countries. The presence of such firms in a country also can drive IT investment by local firms to compete with, or do business with, multinational corporations who are sophisticated users of IT. Countries with greater inflows of investment, technology and knowledge should experience greater productivity gains.

In addition to policies related to external openness, IT use is influenced by governmental regulation that affects the *cost of telecommunications.* As mentioned above, computer, Internet and telephony use have been found to be positively correlated with physical communication infrastructure. More importantly, access to the internet and other networks is strongly influenced by telecoms cost—especially in developing countries. One study found that the number of Internet hosts in a country was negatively associated with telephone service costs (Oxley and Yeung, 2001). Two cross-country studies indicated that average monthly telephone cost is positively related to internet diffusion in developing countries (Kiiski and Pohjola 2001; Dewan et al. 2010). Various policy studies on telecommunications regulation have indicated that the high cost of telecommunications is a major inhibitor of IT adoption and use, particularly in developing countries, and have advocated greater competition in telecommunications and Internet markets to reduce prices (OECD, 1996, 2002). Low cost access to computers and the internet, in turn enables greater digitization of society and associated productivity gains as digital information and media substitute for the physical movement of information, goods and people.

2.3 Relation to the prior literature

Our work builds on the studies above to make a unique contribution to two streams of research on information technology and productivity. First is the impact of IT investment on productivity at the country level. To our knowledge, this study is the first to find a positive relationship between IT and productivity for developing countries. We have created a unique multi-country database covering 23 years from 1985-2007 that enables us to replicate earlier analysis of IT investment and productivity in developed and developing countries (Dewan and Kraemer 2000). It also enables us to conduct new analysis comparing the earlier 1985-1993 period with 1994-2007, creating a comprehensive picture of IT productivity. In doing so, we contribute entirely new findings to the IT productivity discussion at the cross-country level.

Second, we contribute to understanding of the factors that influence IT productivity in the first such study at the country level. Firm and industry level studies of IT productivity have noted that while IT investment pays off in terms of greater productivity overall, there is considerable variation among firms and industries that warrants explanation. These studies identified two broad sets of factors that influence productivity impacts: complementary factors that are changeable only over the long term and management practices, which can be changed in the short term by managers. Using the research on diffusion of computers and the internet, we identified four factors that might operate in similar fashion at the country level: human capital, telecommunications infrastructure, cost of telecommunications and openness to the global economy. We conjecture that these factors will explain differences in IT productivity payoffs between developed and developing countries, and we find that they do, providing useful implications for government policymakers.

3. Methodology

A two-step analysis is used in this paper. The first identifies the productivity impacts of IT investments and the second assesses the influence of complementary assets and government policy on productivity impacts.

3.1 Production function analysis of IT productivity

We use standard production function analysis to determine the productivity impacts of IT investments in developing countries at two periods in time. The goal is to determine whether longer experience with IT use shows productivity payoffs not present in previous studies. We compare developing countries with developed countries for the same time periods to see whether the productivity gap is growing or lessening.

To estimate productivity impacts, we adopt an inter-country production function of the form

$$Q_{it} = F(IT_{it}, K_{it}, L_{it}; i, t) \qquad (1)$$

In equation 1, Q_{it} is the annual GDP, and we model it as a function of IT capital stock (IT_{it}), non-IT capital stock (K_{it}), and total labor hours employed annually (L_{it}). The i and t following the semi-colon are dummy controls for country and year specific effects. Equation 1 is modeled using a panel dataset that covers 41 countries over 20 years (1985-2004).

Following Brynjolfsson and Hitt (1996) and Dewan and Kraemer (2000), we adopt the Cobb-Douglas production function. These authors have shown that this particular form is a good approximation in the IT and productivity context. Using the production function, we have for Country i ($i = 1, 2, \ldots, N$) in Year t ($t = 1, 2, \ldots, T$):

$$\log Q_{it} = \alpha + \lambda_t + \beta_{IT} \log IT_{it} + \beta_K \log K_{it} + \beta_L \log L_{it} + v_i + \varepsilon_{it} \qquad (2)$$

In the above equation, λ_i is a year dummy that captures the effect of years in the regression, v_i is the country specific effects invariant over time, and ε_{it} is the random error term in the equation that represents the net influence of all unmeasured factors impacting output. One useful feature of adopting the Cobb-Douglas production function is that we can focus our analysis strictly on B_{IT}, B_K, and B_L, which captures the increase (or decrease) in output associated with changes in corresponding input (IT capital, non-IT capital, and labor). In other words, the parameters can be interpreted as elasticity effects of input factors on output as in earlier studies (Dewan and Kraemer 2000).

Equation 2 can be simply estimated using regression techniques that can account for differences among the countries and across time. Generally, there are two types of models for modeling cross-sectional heterogeneity – the fixed effects and random effects model. The random effects model requires stringent assumptions regarding the structure or distribution of the error term that we cannot meet and, therefore, the fixed effects model is adopted in our analysis. However, the fixed effects model requires estimating a series of country-specific effects, v_i, which requires precious degrees of freedom that is taxing on the modest data set we have. We avoided having to deal with a large number of dummy variables by transforming the variables in Equation (2) as deviation from country means, leading to the so called within-country regression. That is, we restated the model as

$$logQ_{i,t} - logQ_{i.} = \qquad (3)$$

$$\beta_{IT}\left(logIT_{i,t} - logIT_{i.}\right) + \beta_K\left(logK_{i,t} - logK_{i.}\right) + B_L\left(logL_{i,t} - logL_{i.}\right) + \varepsilon_{i,t} - \varepsilon_{i.}$$

The within-countries regression, estimated by ordinary least squares, is equivalent to the least squares dummy variables approach (Green 1990).

The above Equation 3 centers on the short-run contemporaneous relationship between IT capital inputs and outputs. To better understand the long-term effect of IT capital and other inputs on output, we also examined the between-country regression. The between-country regression is essentially analysis of the cross-sectional variations performed by restating Equation (2) in terms of country means across sample years as in Equation 4 below.

$$logQ_{i.} = \alpha + \beta_{IT} logIT_{i.} + \beta_K logK_{i.} + \beta_L logL_{i.} + v_i + \varepsilon_{i.} \qquad (4)$$

3.2 Regression analysis of factors influencing productivity

The second step in our framework evaluates factors that might influence the level of productivity payoffs among developing countries. As noted earlier, these include complementary assets (human capital, telecommunications infrastructure) and national policies (openness of the global economy, telecoms pricing). To investigate the impacts of these factors, we split developing countries by each factor into above average and below average groups across all years. Regression analysis was then conducted for each sub-sample to determine each factor's influence on productivity.

4. Data and variables

Our database contains macroeconomic and IT investment data for 41 developing and developed countries from 1985 to 2007 (Table 1).

[Insert Table 1 here]

Data for the current analysis came from four primary sources. Data on IT spending were from the International Data Corporation (IDC, 2007). Gross domestic product information was obtained from Penn World Tables (PWT) version 6.1 (Heston et al., 2009). Although not publicly released, we were also able to obtain data on total capital stock privately from the authors of the Penn World Tables. Labor statistics are from the International Labour Organisation through the World Bank's (2009) World Development Indicators Database Online (hereinafter, World Bank Database). Data on other variables (openness to global economy, foreign direct investment, human capital, telecoms infrastructure and cost of telecommunications) were collected from the World Bank Database (World Bank, 2009) and the World Telecommunication/ICT Indicators Database (ITU, 2010).

Dollar values of capital stock, IT capital stock, non-IT capital stock and GDP/capita are expressed in international dollars. The "international dollar" refers to currency conversion based on purchasing power parities so that real quantity comparisons can be made across countries and time (Heston et al., 2009). An international dollar has the same purchasing power over total U.S. GDP as the U.S. dollar in a given base year (2005 in PWT 6.3).

The first step in creating variables for the production function analysis was to compute the key capital stock series for each country over time. Penn World Tables provided *Total capital stock* up to the year 2004. To complement the series, we estimated the total capital stock for years 2005-2007 by estimating the following equation for each country:

$$TKS_t = \alpha + \beta_1 I_t + \beta_2 TKS_{t-1} + \varepsilon$$

We further computed total IT capital stock and non-IT capital stock.

Total IT capital stock was computed from the aggregation of annual total IT spending available from International Data Corporation (IDC, 2007). We have annual IT spending from 1985 through 2007. To compute stock, we stretched the series back to 1975 based on the price adjusted logistic curve used in Gurbaxani and Mendelson (1990). The flow was aggregated into net IT stock using the depreciation profiles based on the work of Oliner (1996). In computing the depreciation profile for total IT from its component depreciation profile, we used the following weights: Mainframes (1/3), PCs (1/3), Printers, Displays & Storage Devices (1/9 each).

Total Non-IT capital stock was computed by subtracting total IT stock from total capital stock for each country over time.

The last factor of production is *Labor*. We computed billions of total labor hours per year for each country by taking the total labor force, adjusted by the unemployment rate, and multiplied by the average number of worker hours.

We next created the variables for the second step in our analysis framework—the regression analysis of complementary assets and government policy.

Telecommunications infrastructure was measured by the amount of telecommunication investment as a percentage of GDP from the World Telecommunications/ICT Indicators Database (ITU 2010). We use investment rather than the teledensity measure (mainlines per 100 people) used in diffusion studies because investment captures mobile telephony and the internet as well as mainlines. These newer technologies have been found to be especially important to enabling greater IT use in developing countries, as their complementary cross-technology diffusion effects are significantly stronger in developing countries than in developed ones (Dewan et al. 2010).

Human capital was measured by percent tertiary school enrollment (of gross school enrollment) for each country from the World Development Indicators Database (World Bank 2009). We use tertiary education rather than average years of schooling used in other studies because it was found to make a difference for developing countries whereas average school years did not (Kiiski and Pohjola 2001).

Openness to the global economy is measured by the total amount of foreign direct investment (FDI) as a percent of GDP from the World Development Indicators Database (World Bank 2009). We use FDI rather than various trade measures (commodity imports, trade as percent of GDP) or foreign aid, because FDI generally flows from developed to developing countries and is a better measure of channels of communication, cross-border learning and the transfer of know-how to developing countries than is simply the amount of trade.

The *cost of telecommunications* is measured by the business monthly cost of a telephone subscription from the World Telecommunications/ICT Indicators Database (ITU 2010). We use business cost rather than consumer cost, which is more common in diffusion studies, because diffusion tends to flow from organizations (business, government, schools) to individuals and households (Venkatesh 1996). In developing countries, these organizational users are important to achieving revenues so that costs can be brought down for individuals and households, to start a virtuous cycle of increased demand, revenues and investment, which supports price reduction (Kiiski and Pohjola 2001).

The descriptive statistics for our data are presented in Table 2.

[Insert Table 2 here]

Figure 1 and 2 present scatter plots of the country-level IT capital investment as a percentage of GDP denominated in 1996 international dollars. Figure 1 shows the picture from 1985-1993 and Figure 2 from 1984-2004. Comparison of the average annual growth rate from the data in the figures indicates that both developed and developing countries have increased the level of IT investments in the latter period (27% and 31% respectively), and that the developing country increase has been considerably greater in the second period than earlier (32% versus 22%). We therefore expect IT impacts to be more likely to show up in the productivity analysis for developing countries in the latter period.

[Insert Figures 1 and 2 Here]

5. Results

5.1 IT investment and productivity

Table 3 presents the results of our GLS estimation. In the developing country sample (hereinafter DG), the point estimate of IT capital elasticity pooling across all time periods is .001 and not significant (t=.219, p>.05). Splitting the sample into 2 time periods, we found that during 1985-1993 time periods, DG IT capital elasticity is negative at -.012 and also not significant (t=-1.255, p>.05). This corresponds to findings from Dewan and Kraemer (2000) for a similar dataset. However, in the later time period 1994-2007, IT capital in DG sample turned around and became positive at .019 and is significant (t=2.944, p<.05).

The non-IT capital shows a positive, significant effect across both time periods at .649 and .546 respectively (p.>.0001). It is worth noting that while the factor share of non-IT capital is 36.6 times that of IT capital in the DG sample (1994-2007), its elasticity is only 24.8 times, suggesting a slight increasing return to scale. We also note that for labor in the DG sample, the elasticity increased from .095 (t=2.017, p<.05) to .246 (t=2.844, p<.05), indicating a significant increase in labor productivity during this time period.

In the developed country sample (hereinafter DD), the effect of IT capital on output is positive and significant across all time periods examined. However, we found a slight downward trend from 1985-1993 of .014 (t=4.355, p<.001) to .008 (t=4.026, p<.001) in 1994-2007. This is consistent with the findings of Dewan and Kraemer (2000), and might indicate some diminishing return effects. Non-IT capital showed positive and significant effects at .515 and .456 across the two time periods (t=17.237 and 16.943, ps<.001 respectively). Again, the point estimates showed slight decreasing return to scale, but not as big as in the case of IT capital. Labor elasticity is positive and significant at .645 and .661 for the two time periods respectively (t=10.830 and 13.391, ps<.001), which indicates slight increasing returns to scale.

[Insert Table 3 here]

To further confirm our findings, we assess the robustness to various model specifications. We examined the robustness to autocorrelation by estimating the AR(1) model which allows for heteroskedasticity and contemporaneous correlations between cross sections. Results for AR(1) models are reported in Table 4. Compared to within country regression results reported in Table 3, there is no noticeable difference in direction or significance of the estimates. We note that the estimate of IT capital is higher in the AR(1) specification, but this does not change the implication of the results.

[Insert Table 4 here]

Further, we also examine robustness to simultaneity or endogeniety of the input variables (manifested in correlation between regressors and error term). Labor input is the most susceptible to this problem because it is most responsive to fluctuations in GDP since any change may trigger contemporaneous adjustment in the labor force. To deal with this, we use an instrumental variable for labor input (lagged labor, GDP, and all other exogenous variables) and estimate the model as 2SLS. Results of 2SLS are reported in Table 5. Compared to Table 3, we did not observe differences in the direction or significance of the estimates across DD and DG samples and across time periods. This indicates simultaneity is not a critical issue in the estimations.

[Insert Table 5 here]

Next, we examined the long run effect of IT capital on output. Table 6 reports the between country regression results. As expected, in the DD sample, all input factors are positive and significant. However, the in the DG sample, only IT capital is not significant, although it is in the positive direction.

[Insert Table 6 here]

5.2 Complementary assets and government policy

Overall, the results indicate that in the early sample years, IT capital exhibits strikingly different effects between developed and developing countries in that IT capital produced significant gains in developed countries only. It is worthwhile therefore to investigate what happened in some of the developing countries that changed the IT capital returns structure. We do so by splitting the DG sample for years 1994-2007, the time period when they are showing positive effect of IT capital on output, into subsamples based on several measures – business monthly telephone subscription charges, tertiary enrollment, foreign direct investment, and telecom investments. For business monthly telephone subscription charges, we split the sample by whether the country experienced lower average monthly charges between 1994 and 2007 or not. For tertiary enrollment, we compute the percentage of increase and split along the median. For FDI and telecom investments, we split the sample to above and below average investments as percentage of GDP. We then ran separate regressions for each of the sub-samples and report the results in Table 7.

[Insert Table 7 here]

As Table 7 shows, we find consistent patterns in the effect of IT capital on output. For the DG sample, when countries have lowered their monthly telephone charges, have above median improvement in their tertiary enrollment, and have above average FDI and telecom investment, IT capital tends to positively and significantly impact output. In particular, countries with above median growth in tertiary enrollment appear to have the largest magnitude of impact for their IT capital (.046, t=6,941 $p<.001$), followed by countries with above average telecom investment as percentage of GDP (.038, t=4.530, $p<.001$).

On the other hand, we also observed that countries that did not experience lower telecommunication cost during this time period, had below median improvement in tertiary school enrollment, or were below average in FDI or telecom investments, did not show any correlation between IT capital and output (all p.>.1) . This is consistent with our expectation that as more foreign investment pours in, multinational companies will bring their best IT practices with them into the developing countries and help their local partners to adopt better practices. In turn, these practices gradually diffuse through supply chains into the economy thereby helping to boost the output from IT investments. Similarly, as the quality of labor improves through education, countries are better able to take advantage of IT investments to produce output gains.

5. Conclusion

This study revisited the issue of whether IT investment leads to greater economic output, looking across a large sample of developed and developing countries. With 41 countries over 23 years, this is the largest study of IT and productivity at the national level that we are aware of, and the first to include data from the 1994-2007 period. During this period, the nature of IT changed significantly with the widespread adoption of the Internet, electronic commerce, PCs, client-server computing, smart phones, and a variety of enterprise and inter-organizational systems. Also, IT investment in the developing world grew at a dramatic pace, lessening the gap in IT capital between developing and developed countries. These changes were accompanied by rapid globalization of manufacturing and services, as well as greater flows of capital and labor across borders. In such a changing environment, we might expect to see new relationships between IT and productivity, and we did.

5.1 Discussion

The findings in this study include two important new results. First, there is strong evidence that developing countries are now enjoying productivity growth associated with IT investment, as the developed world had experienced in earlier years. This addresses one of the major concerns raised by prior studies of IT and productivity, which had failed to find such a relationship and thus raised questions about whether the majority of the world's population was being left out of the IT productivity story. For the first time, there is now empirical evidence that the positive impacts of IT at the country level extend to both developed and developing countries.

It is possible that IT investment in developing countries has contributed to economic and productivity growth for decades, but did not show up because of IT's lower share of total capital stock in these countries. This speculation is supported by U.S. studies, which argue that there had been significant and positive impacts from IT investments for developed countries for decades, but that the impacts of IT capital investment were low because of its lower share of total capital stock (Jorgenson, 2001; Oliner and Sichel, 2000; Bosworth and Triplett, 2000).

Second, we find evidence that four factors influence the relationship of IT investment to productivity in developing countries. Developing countries with above average improvement in tertiary education and better telecommunications infrastructure, falling telecommunications prices and greater foreign direct investment, exhibited greater productivity impacts. This suggests that the impacts of IT depend not only on the level of use, but on the availability of complementary resources and government policy supporting technology use. Although these relationships had been posited in the literature previously, and had been found to influence IT investments (Dedrick and Kraemer, 2001), this study provides the first empirical evidence linking them with productivity.

5.2 Implications

These results have both academic and policy implications. For IS researchers, they reduce concerns that the strong relationship of IT investment to productivity at the national level was specific to richer countries and thus limited in applicability. The finding that developing countries only began to realize measurable payoffs from IT investment in more recent years suggests that there may be some critical level of IT capital stock, or some minimum level of accumulated experience (human capital) required before such gains become evident. Indeed, our finding that IT played a very important role in productivity post-2004 for developing countries is consistent with the capital stock explanation and with previous research (Triplett and Bosworth, 2002).

Similarly, our finding about the role of accumulated experience is consistent with other research that examined productivity differences among countries. Kryiacou (1992) concluded that economic growth was associated with an abundant stock of human capital, and that convergence of developing and developed countries only occurs if sufficient levels of human capital are accumulated. It is possible that the same is true for more IT-specific knowledge associated with experience in IT use.

For policymakers in developing countries, the findings provide evidence that their IT investments are likely to lead to productivity gains, and thus to higher sustainable economic growth rates. These economic impacts provide the case for policies to support IT use, and to avoid policies that discourage use such as raising taxes or tariffs on computing or communications equipment, raising telecommunications prices, raising barriers to Internet use, or favoring domestic IT production at the expense of use. The findings also point to the importance for developing countries of policies to increase tertiary education and telecommunications investment and to reduce telecoms costs in order to realize greater benefits from IT investment. These policies are desirable on their own merits, but the fact that such resources enhance the value of IT is another reason to pursue them.

Our findings plus those of Kiiski and Pohjola (2001) and Dewan et al (2010), suggest that countries should consider strategies to create "clusters" of related IT technologies for greater impact in places such as schools, libraries, or community centers. Rather than just promoting a single technology, considerations should be given to providing a package of technologies (e.g., PC or other access device, software, low-cost or free Internet access, local networking) and training for users.

Finally, the study has identified critical areas for future research. The significant moderating effect of complementary assets and government policy on the productivity impacts of IT shows that better models need to be developed to capture other factors that might influence IT productivity. There are rich opportunities for further research in quantifying the cumulative impacts of IT investment and experience, and in identifying other complementary resources or other country-level variables that might affect the relationship of IT to productivity.

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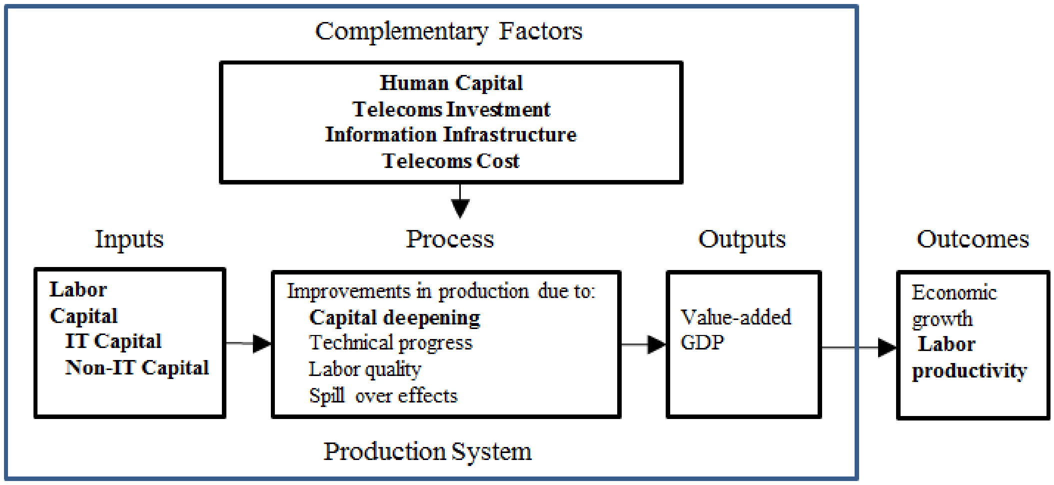
Figure 1. Analysis framework



Adapted from Dedrick, Gurbaxani, Kraemer (2003).

Table 1: Countries Used in the Analysis

Developing Countries	Developed Countries	
1. Argentina	1. Australia	17. New Zealand
2. Brazil	2. Austria	18. Norway
3. Chile	3. Belgium	19. Portugal
4. China	4. Canada	20. Singapore
5. Columbia	5. Denmark	21. Spain
6. Egypt	6. Finland	22. Sweden
7. Hungary	7. France	23. Switzerland
8. Indonesia	8. Germany	24. Taiwan
9. India	9. Greece	25. United Kingdom
10. Malaysia	10. Hong Kong	26. United States
11. Mexico	11. Ireland	
12. Philippines	12. Israel	
13. Poland	13. Italy	
14. Thailand	14. Japan	
15. Turkey	15. Korea, South	
16. Venezuela	16. Netherlands	

Note: Countries are listed as developed or developing based on their status at the beginning of the 1994 time series, as defined by the IMF World Economic Development Outlook (2010). This is consistent with, but different from the Dewan and Kraemer (2000) definition, which took 1985 as the base year. We choose 1994 as the base year because some countries in our sample (and the Dewan and Kraemer sample) have moved from developing to developed status (Greece, Korea, Portugal, Taiwan) since 1997. We have also added five countries, which were not in Dewan and Kraemer, to the developing country category (Brazil, China, Hungary, Indonesia, Malaysia and Switzerland) because suitable data became available.

Table 2: Descriptive Statistics: Average of Country Averages for Each Period

	Developing Countries			Developed Countries		
	1985-2007	1985-1993	1994-2007	1985-2007	1985-1993	1994-2007
GDP per capita	$6,111	$4,487	$7,735	$20,624	$15,362	$25,885
Total Non-IT Capital Stock	$1,114B	$764B	$1464B	$2,035B	$1,697B	$2,381B
Total IT Capital Stock	$21.76B	$5.44B	$38.09B	$80.73B	$37.17B	$116.84B
Total Annual Labor Hours	199B	188B	209B	29B	28B	30B
FDI/GDP (Inflow)	2.27%	1.37%	3.16%	3.23%	1.59%	4.80%
Telecom Investment/GDP	0.73%	0.58%	0.89%	0.63%	0.63%	0.64%
Bus. Mo. Tel. Subscription	$11.34	$11.60	$11.11	$16.87	$15.45	$18.30
Tertiary Enrollment	--	--	28.78%	--	--	57.79%
Number of Countries		16			26	

Note: Tertiary enrollment data only available for years 1995-2007.

Table 3: Within Country Regression

	Developing Countries			Developed Countries		
	1985-2007	1985-1993	1994-2007	1985-2007	1985-1993	1994-2007
β_{NIT}	0.625***	0.649***	0.546***	0.495***	0.515***	0.456***
	(18.996)	(10.844)	(13.924)	(24.377)	(17.237)	(16.943)
β_{IT}	0.001	-0.012	0.019**	0.010**	0.014***	0.008***
	(0.219)	(-1.255)	(2.944)	(2.427)	(4.355)	(4.026)
β_{L}	0.186*	0.095*	0.246**	0.696***	0.645***	0.661***
	(2.776)	(2.017)	(2.844)	(18.193)	(10.830)	(13.391)
DF	323	123	200	584	220	363
Adj. R^2	0.958	0.965	0.954	0.976	0.916	0.949

Note: t-statistics are in parentheses, and *, **, *** denotes significance at 10%, 5%, and 1%, respectively.

Table 4: Robustness Check for Autocorrelation AR(1)

	Developing Countries			Developed Countries		
	1985-2007	1985-1993	1994-2007	1985-2007	1985-1993	1994-2007
β_{NIT}	0.554***	0.556***	0.662***	0.486***	0.668***	0.304***
	(7.350)	(4.296)	(6.421)	(9.397)	(8.330)	(4.470)
β_{IT}	-0.013	0.007	0.041*	0.046**	0.041*	0.094**
	(-0.850)	(0.311)	(1.947)	(2.225)	(1.809)	(2.104)
β_L	0.254**	0.263**	0.440***	0.621***	0.577***	0.675***
	(2.384)	(2.339)	(3.496)	(11.073)	(6.832)	(8.981)
DF	291	107	184	509	194	337
Adj. R^2	0.788	0.796	0.791	0.870	0.885	0.867

Note: t-statistics are in parentheses, and *, **, *** denotes significance at 10%, 5%, and 1%, respectively.

Table 5: Robustness Check for Simultaneity 2SLS

	Developing Countries			Developed Countries		
	1985-2007	1985-1993	1994-2007	1985-2007	1985-1993	1994-2007
β_{NIT}	0.625***	0.683***	0.545***	0.472***	0.466***	0.445***
	(18.146)	(10.011)	(13.780)	(21.276)	(12.986)	(15.892)
β_{IT}	0.002	-0.014	0.018**	0.009**	0.011***	0.008***
	(0.376)	(-1.379)	(2.918)	(2.240)	(3.395)	(3.867)
β_L	0.213*	0.243*	0.234*	0.684***	0.632***	0.640***
	(2.361)	(2.258)	(2.533)	(15.771)	(8.609)	(11.870)
DF	307	107	200	558	194	363
Adj. R^2	0.956	0.961	0.954	0.972	0.884	0.945

Note: t-statistics are in parentheses, and *, **, *** denotes significance at 10%, 5%, and 1%, respectively.

Table 6: Between Country Regression 1985-2007

	Developing Countries	Developed Countries
β_{NIT}	0.444*	0.437***
	(2.675)	(3.745)
β_{IT}	.114	0.173*
	(0.813)	(1.990)
β_{L}	0.314**	0.391***
	(4.299)	(5.419)
DF	12	22
Adj. R^2	0.983	0.995

Note: t-statistics are in parentheses, and *, **, *** denotes significance at 10%, 5%, and 1%, respectively.

Table 7: Developing Countries Sample Split for years 1994 – 2007

	Bus. Mo. Tel. Subscription		Tertiary Enrollment		FDI as % GDP		Telecom Investment as % GDP	
	Lower	Not Lower	Above Median Increase	Below Median Increase	Above Avg.	Below Avg.	Above Avg.	Below Avg.
β_{NIT}	0.626***	0.168*	0.583***	0.644***	0.569***	0.197**	0.593***	0.313***
	(12.835)	(2.123)	(13.507)	(9.374)	(11.860)	(2.644)	(11.202)	(5.455)
β_{IT}	0.020	-0.004	0.046***	-0.002	0.026**	-0.005	0.038***	-0.007
	(2.324)*	(-0.396)	(6.941)	(-1.667)	(3.056)	(-0.560)	(4.530)	(-0.772)
β_{L}	0.190*	0.171*	0.328**	0.315*	0.338**	0.332*	0.371**	0.202*
	(2.107)	(2.110)	(2.413)	(2.153)	(3.478)	(2.128)	(2.598)	(2.182)
DF	110	90	85	114	124	76	75	124
Adj. R^2	0.965	0.947	0.946	0.960	0.956	0.966	0.957	0.945

Note: t-statistics are in parentheses, and *, **, *** denotes significance at 10%, 5%, and 1%, respectively.

Appendix Table A-1. Variables, measures and data and related to prior studies

Variable	Measure	Data source	Prior studies
IT productivity			Studies of productivity payoffs from IT investments
Inputs			
Total capital stock	Total capital stock	Penn World Tables	Lichtenberg, 1995; Brynjolfsson & Hitt 1996; Dewan & Min 1997; Dewan & Kraemer 2000.
IT investment	Annual IT spending	International Data Corporation	Ibid.
IT capital	IT capital stock	Calculated	Ibid.
Non-IT capital	Non-IT capital stock	Total capital stock – IT capital stock	Ibid.
Labor	Total labor hours	Calculated	Ibid.
Output			
Productivity	Elasticity of demand	Production function	Ibid.
Factors influencing productivity payoffs			Studies of factors influencing diffusion of computers and the Internet
Human capital	Percent tertiary school enrollment of gross school enrollment	World Development Indicators Database	*Education: (1) Attendance in University Education:* Kiiski & Pohjola 2001 *(2)*Average years of schooling of workers age 25 and over: Robison and Crenshaw 2002, Shih et al., 2007 (3) Average years of schooling for the population over age 15: Kiiski & Pohjola 2001; Caselli & Coleman 2001.
Telecommunications infrastructure	Telecommunications investment as percent of GDP	World Telecommunications ICT Indicators Database	*Teledensity* (mainlines per 100 people) Oxley & Yeung 2001, Robison and Crehshaw 2002, Kraemer and Dedrick 1994
Cost of telecommunications	Monthly business telecoms cost	World Telecommunications ICT Indicators Database	Internet access costs (average cost to users to access the Internet for 20 hours per month at peak rates): Kiiski & Pohjola 2001 Telephone access costs (monthly subscription rates plus cost of 30 minute call): Kiiski & Pohjola 2001
Openness to the global economy	Foreign direct investment	World Development Indicators Database	*Inward foreign direct investment as percent of GDP*: Shih et al., 2008 Total commodity imports per capita from OECD nations: Shih et al., 2008; Caselli & Coleman 2001. Trade as percent of GDP: Shih et al., 2008 Foreign aid as percent of GDP: Shih et al., 2008.

Figure 1. Scatter plot between average annual IT investment as a percent of GDP against mean GDP per worker, developed and developing countries, 1985-1993

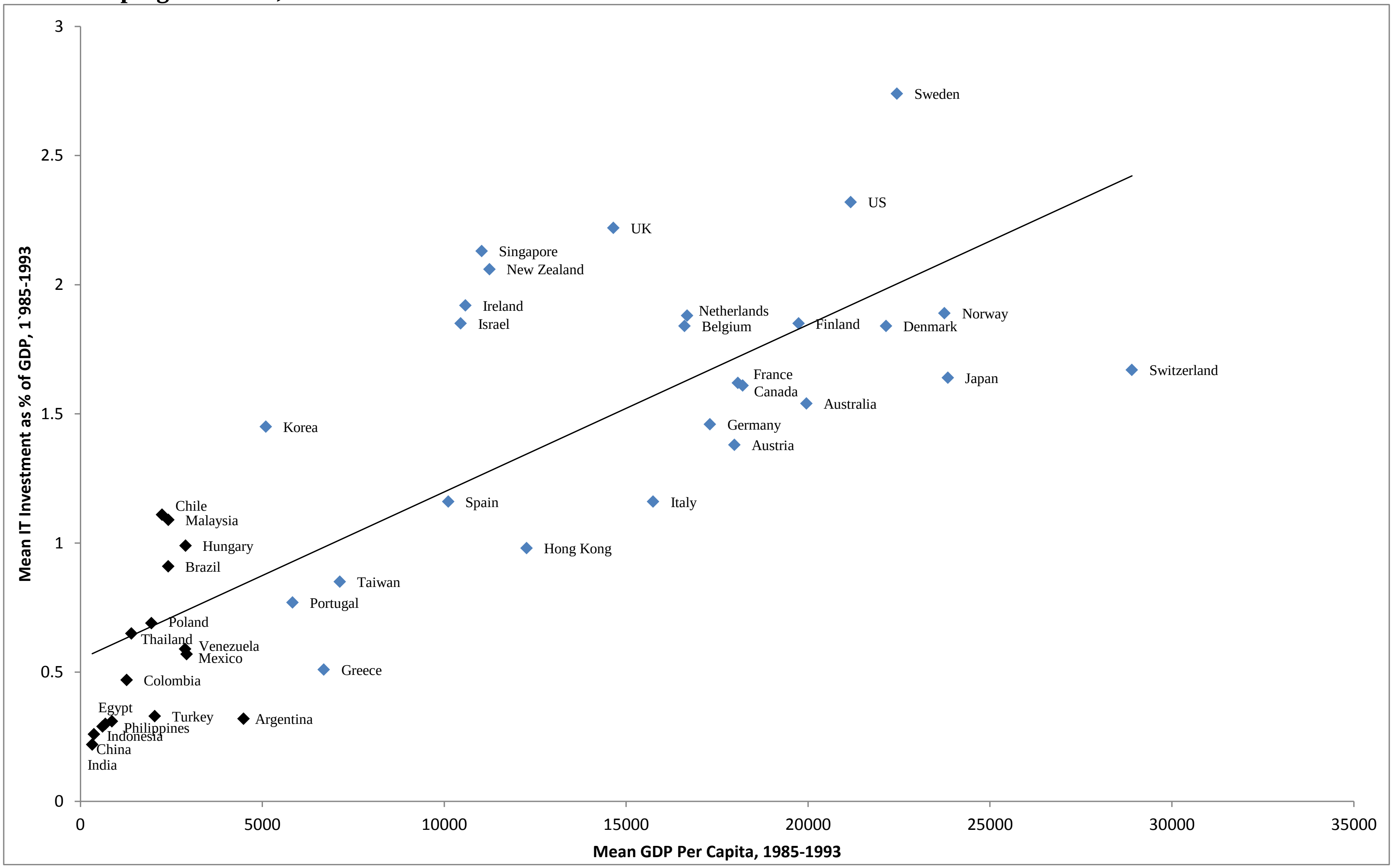


Figure 2. Scatter plot between average annual IT investment as a percent of GDP against mean GDP per worker, developed and developing countries, 1994-2007